



Overcoming Information Overload in the Cockpit

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Executive Summary

Problem Definition The Army's Program Executive Office (PEO) - Solider, Project Manger Air Warrior, is focused in part on identifying and fielding new technologies that will convey the most important information to pilots, when they need it, and in a more efficient and effective manner than is currently being done across Army Aviation. The ever increasing complex nature of flying and managing an aircraft, especially during an event which degrades pilot awareness, demands a constant search for better ways of portraying aircraft data to the crew members. The objectives of this study were to determine a hierarchy of information requirements for pilots at different times throughout the course of a mission, research better ways to relay that information to pilots by finding new intuitive display technologies, tactile technologies, and alternate heads-up-display symbology layouts, and finally, to determine, through the use of a non-human-in-the-loop discrete event simulation, if these new technologies have a significant impact on increasing pilot situational awareness while at the same time reducing both overall and individual resource (visual, cognitive, auditory, fine motor, and speech) workload on the crew.

Technical Approach The first step in moving towards a solution to this problem is understanding that information requirements for pilots are heavily dependent on mission, aircraft, and situation. What bits of information that help pilots fly safely are in constant flux. Therefore, in order to answer the question at hand, we must narrow the scope of the problem from all pilots in all airframes at every instant in time down to specific aircraft, flying a specific mission, at a specific time. With this in mind, the following bullets lay out the methodology that was employed in this study:

- Develop two different scenarios in which to frame the problem and answer the study objectives, while keeping them general enough to apply to different rotary-wing aircraft flying different missions.
- Perform a functional analysis on the scenarios in order to both develop a task list in which we will then map information requirements to, and create a model that will serve as the input for the discrete event simulation.
- Develop surveys and conduct interviews with subject matter experts (pilots) and perform a statistical analysis of the results in order to establish priority information requirements for pilots at different times throughout the mission.
- Concurrently research intuitive display technologies and alternative symbology layouts for the heads up display with the potential for increasing pilot situational awareness and reducing workload.
- Using the scenarios and functional analysis completed earlier in the study, create both scenarios in the discrete event simulation using the current technology available to pilots, and then, utilizing the results of the state-of-the-art technology survey, create new cockpits (based on the same scenarios) by adding new, intuitive display technologies.
- Compare the overall and individual resource workloads in both scenarios between the current cockpit design and the alternate one based on new technologies, using statistical techniques in order to do so.

Overcoming Information Overload

Results The survey was designed in three parts in order to establish a hierarchy of information requirements for pilots given aircraft type, mission, and situation. The survey results are too numerous to report here, but hopefully we were able to capture the desired data. The state-of-the-art survey of intuitive display technologies focused, for the most part, on tactile technologies. In the end, the most viable solutions were those offered by the Tactile Situation Awareness System, a newly developed soft-actuator technology whose primary advantages were the quality of the tactor signal, simplicity, and flexibility, and the addition of 3D audio. The alternative heads up display symbology survey results showed a way to create an optimal symbology layout based on the concepts of learned habit patterns and a concept called Layout Appropriateness, in which the “appropriateness” of a given layout is computed by weighing the cost of a sequence of actions by how frequently the sequence is performed. The final part of the study involving the use of a non-human in the loop discrete event simulation to compare workloads in the current cockpits, and ones designed with new technologies, showed beyond doubt that the implementation of intuitive display technologies significantly reduces both the overall and individual resource workload on pilots and copilots alike.

Contents

1	Background	1
2	The Problem	1
2.1	Objective	1
2.2	Approach	2
3	Scenario Development and Functional Analysis	3
3.1	Scenario 1 & Functional Analysis (UH-60: Deliver Internal Load)	3
3.2	Scenario 2 & Functional Analysis (AH-64D: Convoy Security / Hasty Attack)	3
4	Surveys	6
5	Intuitive Display Technology Survey	8
6	Alternative HUD Symbology Layout Survey	12
7	IMPRINT Simulation Configuration	15
8	Simulation Results	17
8.1	Blackhawk	17
8.2	Apache	21
9	Recommendations / Conclusions	21

1 Background

In a survey dating from 1987-1995 of all 970 U.S. Army rotary-wing mishaps, 30% were considered to have had spatial disorientation (which includes drift and/or descent in hover, taxi and hover taxi, IMC related events, recirculation, flight into the ground, and flight over water) as the major or contributing factor (Braithwaite, 1995). In an average year, the costs of these spatial disorientation accidents are 14 lives lost, and \$58 million worth of equipment loss (McGrath, 2004). Consequently, there is significant interest from U.S. Army Aviation as a whole in finding ways to reduce these numbers, and to make the inherently dangerous task of piloting and managing a complex system such as a rotary-wing aircraft both easier and safer for the crew. One organization with vested interest in this topic is the U.S. Army's PEO Soldier - Air Warrior. Their primary mission is to develop, procure, field, and sustain the highest quality aviation life support equipment for U.S. Army aviators and crew members, and also to provide the aviation community with the proper equipment when they need, where they need it, train them to use it effectively, and to sustain the equipment. PM Air Warrior integrates equipment and aircrew with systems such as body armor, helmet mounted displays, survival equipment, micro-climate cooling garments, electronic data managers, etc. . . and also integrates aircrew, systems, and aircraft with cockpit air bag systems, aircraft wireless intercom systems, and helicopter oxygen systems. In relation to this study, PM Air Warrior is trying to identify what information is important to pilots, and better, more intuitive, and more efficient ways of presenting that information to pilots, at the time when they need it most. Pilot performance and aircraft safety are totally dependent of situational awareness (SA), which can be amplified by reducing pilot workload and increasingly data availability that are required for safe operations (Olson, 2007).

2 The Problem

Both the amount of information available to pilots / copilots, and the amount of information that they process throughout the course of a mission are substantial. But not all bits of information are created equal. Are some pieces of information more important to pilots / copilots than others? And also, are there better ways to present that information (i.e., different technologies or symbologies) to pilot / copilots than is currently being done throughout Army Aviation? Another issue that pilots / copilots must battle constantly is information overload. With all that is going on in a cockpit, especially during some kind of non-standard event such as bad weather, aircraft malfunctions, in-flight change of mission fragmentary orders, or being engaged by enemy ground fire, pilots / copilots can quickly become overloaded by the sheer amount of information coming into the cockpit. So the issue then becomes, are there ways to reduce this workload? Can workload be reduced or shifted to another resource by the introduction of new and better technologies? And if and when these new technologies are developed, how do we measure the change in workload between the "old" cockpit and the "new" one, and is the reduction significant?

2.1 Objective

The objectives of the study are threefold. One, identify and establish a hierarchy of information requirements for pilots / copilots. Two, research and identify current commercial state-of-the-art intuitive display technologies and research possible alternative Heads Up Display (HUD) symbology layout and design, and three, calculate the visual, cognitive, auditory, motor, speech, and tactile workload on pilots / copilots and determine if, how, and where workload can be reduced by changing user interface elements and display technologies.

2.2 Approach

Information requirements for pilots / copilots are clearly dependent upon what type of aircraft is being flown, what the pilot / copilot role is during the mission, what type of mission they are flying, and at what specific time during said mission we are talking about. An Apache pilot flying an attack mission has much different information needs than a Chinook pilot does flying an air assault mission. The former is concerned primarily with angle of attack, enemy and friendly location, and munitions selection, while the later is focused more on time, distance, and heading in order to make their time on target. During take-off, a Blackhawk pilot is concerned about different things than they are when reacting to an aircraft malfunction. Consequently, in order to answer the question at hand, we must develop a specific framework in which to operate. Perhaps the two most common missions currently being flown in the Global War on Terror (GWOT) are a deliver internal load (air assault) mission with a Blackhawk, and a convoy security / react to troops in contact mission with an Apache. These two scenarios are what we'll use in order to address the project objectives. The reason that only these two missions will be considered here is a function of time. Considering all airframes (i.e., Apaches, Blackhawks, Chinooks, Kiowas, fixed wing, etc...) and all the mission types that each is required to fly (i.e., transporting internal loads, external loads, MEDEVAC, deep attack, reconnaissance, security, etc...) would have taken too long, and was beyond the scope of this study, but the hope is that these two missions are general enough to capture a significant number of tasks and workload that occur across all missions and airframes.

To meet the first project objective, we conducted a functional analysis of both scenarios which allowed us to capture a significant number of the tasks that the pilot / copilot execute during the course of the mission, and at the same time, allowed us to map those tasks to information requirements that we then had pilots rank in order of importance through interviews and surveys. By determining "all" of the pilot / copilot tasks, we then asked the question of "most im-

portant" ones, and hopefully established some kind of hierarchy of information requirements for pilots given the scenarios we're operating in. Secondly, the functional analysis developed here served as our input model when we measured the workload on pilots / copilots using a discrete event simulation.

Alternative display technologies that were looked at during the second part of this study focused primarily on the current state-of-the-art in commercial tactile interfaces, although 3D audio and auditory displays were also looked at. Currently, pilots receive most of their information from auditory and visual cues that have the potential to, and indeed do, overload the pilot, which in turn can lead to reduced performance and issues with safety (Castle, 2002). Utilizing the often ignored sense of touch, which currently the pilot / copilot receive no explicit input from the aircraft to, tactile displays can effectively be used to offload the visual and auditory systems, and simply shift or reduce the workload to another sensory input. These tactile display technologies provide communication through stimulation of the skin surface, pressures felt in the muscles of the body, temperature changes, or even pain (Castle, 2002). The other piece of the second study objective was looking at better ways of portraying information to pilots, specifically within the HUD. Here we were researching ways to improve the symbology, layout, color scheme, etc... of the current displays that are used in the HUD in order to improve pilot situational awareness.

The third and final part of this study involved calculating the workload on pilots / copilots in order to determine if, how, and where workload can be reduced by changing user interface elements to tactile display technologies. These workload calculations were done via a discrete event simulation called the Improved Performance Research Integration Tool Pro, Version 1.0 (IMPRINT), that was developed by the Army Research Lab's (ARL) Human Research and Engineering Directorate (HRED) in conjunction with Alion, Science and Technology, Inc. The simulation allows the user to calculate the amount of workload experienced by a warfighter throughout a mission, to determine whether any warfighters are overloaded, and if so, how we can change it. IMPRINT allows

the user to add specific interface elements (controls and displays) that warfighters interact with, and the manipulation of auditory, cognitive, fine motor, gross motor, speech, visual, and tactile elements. By calculating the workload in the “current” aircraft / cockpit, and then computing the workload in a “new” cockpit that was altered by including a limited number of tactile display technologies and 3D audio, we were then able to compare the two in an attempt to see any differences, shifting, or reduction in the workload. Shown in figure 1 below is a modified IDEF-0 diagram of the methodology employed in this study.

3 Scenario Development and Functional Analysis

The attempt in both of the scenarios described in the next two sub-sections was to capture every task that the pilot and copilot undertake during the entire course of the mission in order to, in the later part of the study, ensure an accurate measurement of pilot / copilot workload. The functional analysis flow diagrams will serve as the input for the IMPRINT model, and as the basis of the tasks that we map to information requirements during the survey portion of the study.

3.1 Scenario 1 & Functional Analysis (UH-60: Deliver Internal Load)

The scenario developed for the first mission is as follows: You are the Air Mission Commander (AMC) / serial commander (5 aircraft in serial, second of three total serials) for a night air assault (internal load only) with one turn. Weather is not a problem; assume visual flight rules (VFR) and 90% illumination. You’re leaving from a secure pick-up zone (PZ), moving along the primary route to the landing zone (LZ), and then on to a secure airfield. Along the way you experience a minor aircraft malfunction (#1, #2 generator failure), you receive a fragmentary order (FRAGO) to land in a new (unplanned) LZ, and as you are egressing from the new LZ, you come

under fire from a large caliber, radar controlled, anti-aircraft weapon. For this analysis, we are concerned only with pilot / copilot tasks, and we are not taking into account any pre / post-flight operations. You may assume that your experience level is moderate to high, and that all assigned tasks are performed correctly for the duration of the mission. Assume an average speed of 100 knots in airspeed (KIAS) (185 km/h), an ingress distance of 65 km, and an egress distance of 35 km. Both the scenario and functional analysis that follows were developed with significant input from subject matter experts, i.e., Blackhawk pilots with thousands of flight hours in peacetime and during combat operations. Also extensively used in this part of the project were FM 3-04.113, Utility and Cargo Helicopter Operations, TM 1-1520-237-10, Operator’s Manual for UH-60 A/L, and TC 1-237, Aircrew Training Manual for H-60 Series Helicopters, in order to both accurately depict an air assault type mission and pilot / copilot tasks during different parts of the mission, particularly when reacting to aircraft malfunctions.

Figure 2 shows only the top level functional analysis. Appendix A contains the complete breakdown of all of the sub-functions.

3.2 Scenario 2 & Functional Analysis (AH-64D: Convoy Security / Hasty Attack)

The scenario developed for the second mission is as follows: You are the flight lead for a night convoy security mission (2 aircraft). Weather is not a problem; assume VFR and 80% illumination. You’re leaving from a secure Airfield, and moving along Route Brown providing security to a ground convoy moving at 30 mph. Your team will move in a butterfly pattern on the north and south sides of the route. Along the way your aircraft experiences a minor aircraft malfunction (Engine 1 Chips), you receive a FRAGO to provide gunship support to troops in contact (not Danger Close), and engage enemy troops with the 30mm gun who are firing at friendly forces with small arms and rocket propelled grenades (RPGs) from the

Overcoming Information Overload

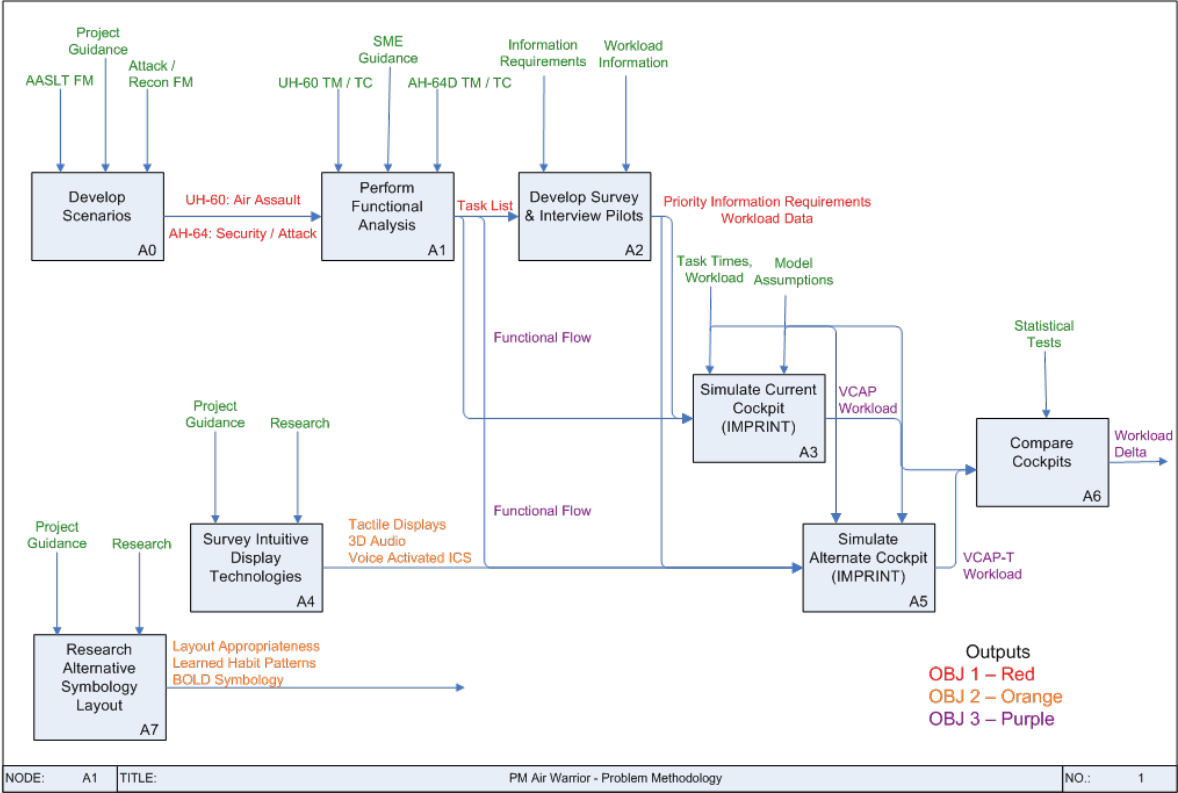


Figure 1: Problem Methodology

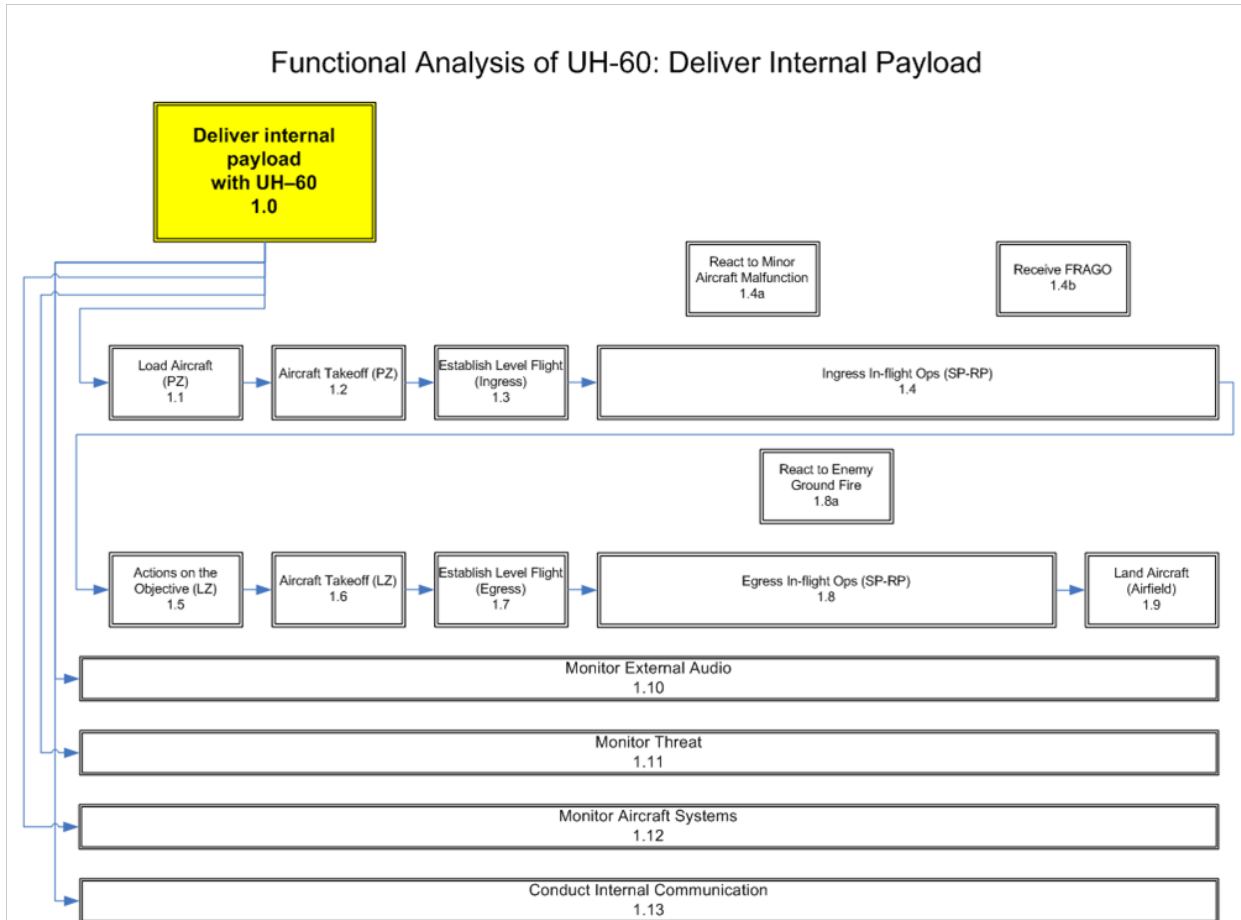


Figure 2: UH-60 Scenario Functional Analysis

objective (medium sized building). Once the objective is secure, you egress back to the airfield. For this analysis, we are not taking into account any pre / post-flight operations. You may assume that your experience level is moderate to high, and that all assigned tasks are performed correctly for the duration of the mission. Assume you are moving at 100 KIAS during the security phase and at 160 KIAS when moving to the troops in contact. As in scenario one, the Apache scenario and the functional analysis that follows were developed with input from Apache pilots with a significant amount of flight hours in peacetime and during combat operations. Also used extensively in this part of the project were FM 3-04.126, Attack Reconnaissance Helicopter Operations, TM 1-1520-251-10, Operator's Manual for Helicopter, Attack, AH-64D Longbow Apache, and TC 1-251, Aircrew Training Manual for AH-64D, in order to both accurately depict a security / hasty attack mission and pilot / copilot tasks during different parts of the mission, particularly when reacting to aircraft malfunctions, actioning weapons and sight systems, and operating the navigational sub-system.

Again, as in the air assault mission, figure 3 shown here represents only the top level functional analysis. See Appendix B for a complete breakdown of all of the sub-functions.

4 Surveys

A three part survey, written in the context of the two scenarios described above, was designed in order to establish a hierarchy of information requirements for pilots / copilots and to collect some data on perceived pilot / copilot workload. The first part of the survey mapped the tasks from the functional analysis to information requirements, and had subject matter experts rank order the information in each sub-function, i.e., at different times throughout the mission, from most important to least. The second part of the survey again had subject matter experts rank order the perceived workload for each resource (visual, cognitive, auditory, speech, and fine motor), from the point of view of both the crew member on

the controls, and the pilot in command, since the perceived workload on each resource may be different for each, and then had them rank order the causes of the perceived workload for each resource for the mission as a whole. The third and final portion of the survey was a free response section in which the SME's were asked about additional information requirements not covered in the survey, additional resource workload not covered in the survey, and potential technologies to incorporate in the aircraft that they thought may be helpful to pilots to improve situational awareness and reduce workload. Both the survey itself and the raw survey data for the UH-60 scenario are provided in Appendices C and E, while the AH-64D scenario survey and raw data can be found in Appendices D and F.

The statistical technique used in the analysis of the Blackhawk data was an Analysis of Variance (ANOVA) in conjunction with a multiple comparison method called Tukey's procedure. An ANOVA will tell you if the population means are significantly different, while multiple comparisons will tell you which means are statistically higher or lower than the others. The mean rank of each information requirement for each sub function was treated as a factor in this ANOVA, and if and when the resulting p-value was less than the significance level, in this case, $\alpha = 0.05$, multiple comparisons utilizing Tukey's Procedure were used to rank order the mean ranks of the requirements from smallest to largest according to the resulting statistically significance differences. A total of 27 Blackhawk pilots were interviewed, and all assumptions of normality were not violated. The small sample size and non-normal nature of the Apache data called for a non-parametric statistical technique, and here we used the Kruskal-Wallis Test, a distribution free version of an ANOVA, where the test results tell us only if the treatment effects are different, but give us no ability to rank order the mean ranks if a difference does exist. A total of 5 Apache pilot were interviewed.

The survey results from parts one and two are given in the figures below. A rank of 1 in the table indicates the most important information requirement, highest resource workload, or cause of workload, that

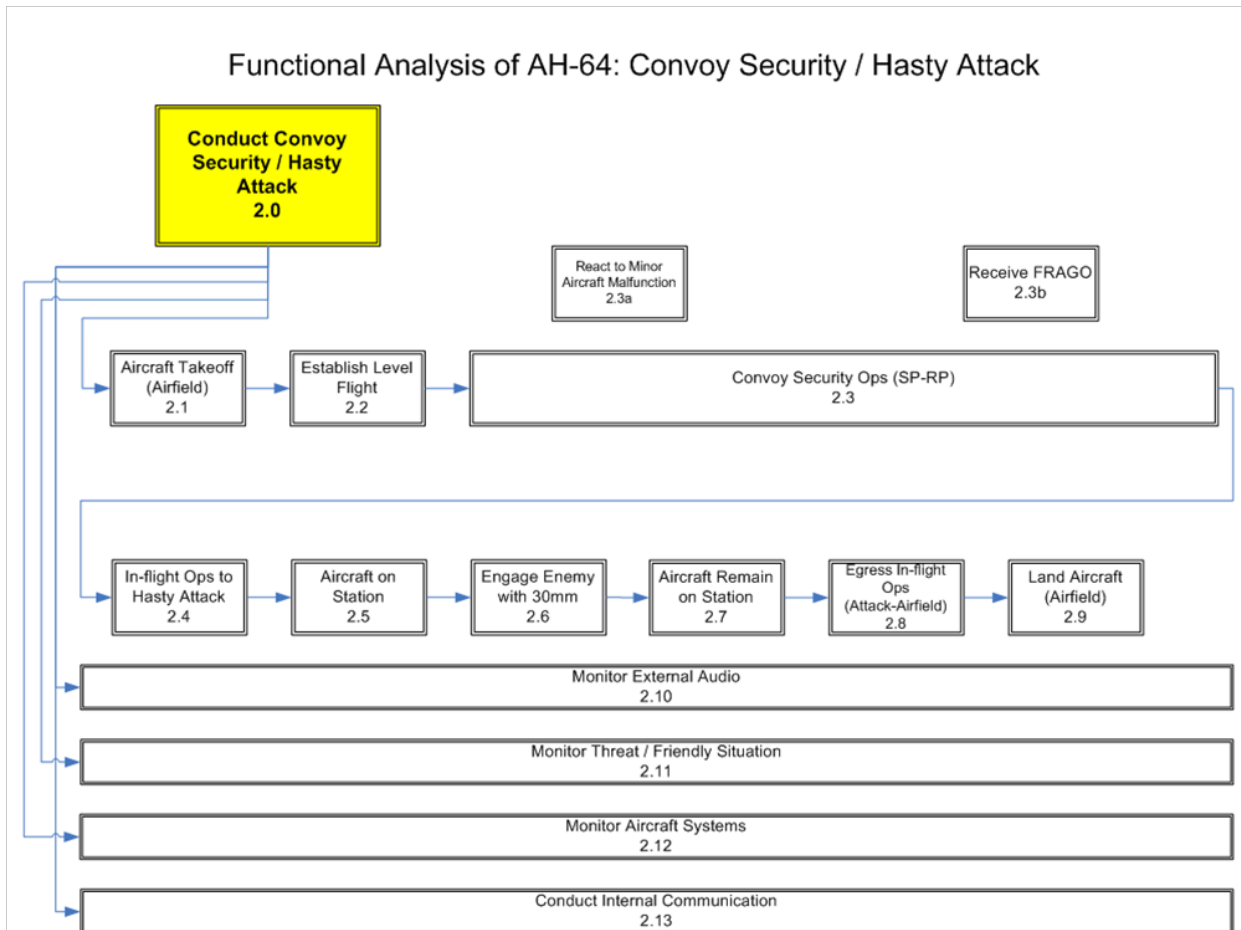


Figure 3: AH-64D Scenario Functional Analysis

pilots recorded, and higher ranks (in number) indicate importance / workload / cause of a lesser degree. Different colors represent statistically significant differences between mean ranks for all of the data in the table, while the same color indicate no significant differences between the mean ranks.

Because of the nature of the Apache data as explained above and the statistical test used, rank ordering as given in figure 5 below are simply raw mean ranking scores. An asterisk indicates statistically significant differences among the means as determined using the Kruskal-Wallis Test.

Part 3 of the survey was a free response section as discussed above. A complete listing of all responses appear in Appendix G. Not everyone who participated in the survey provided responses for part 3. Highlights from the pilot responses include moving map displays with weather data super-imposed on top, a display that provides the sequence for emergency procedures, altitude hold, wireless connections between helmet and communication / night vision system, and digital displays for crew chiefs, to name but a few.

5 Intuitive Display Technology Survey

The second project objective consisted in part of conducting a state-of-the-art survey of intuitive display technologies that have the potential to increase pilot situational awareness and reduce workload. The research effort focused mainly on tactical technologies, although some audio technologies are also presented. The results of this survey are given below.

The Tactile Situation Awareness System (TSAS) is an advanced flight instrument system that uses the haptic sensory channel to provide flight information to pilots. The TSAS system gets data from various aircraft parameter sensors and presents this information via tactile stimulator's, or tactors, that are integrated into the clothing worn by the pilot and copilot. The TSAS has the capability to provide a variety of flight parameters to the crew, including: attitude,

altitude, velocity, threat / target location, acceleration, or heading data (McGrath, 2004). The TSAS comes in a variety of different shapes and both tactor configurations and types. As an example, U.S. Army Aeromedical Research Laboratory (USAARL) study 2004-10 used a off-the-shelf F-22 cooling-heating vest with a pneumatic tactor array consisting of eight columns of two tactors, plus six additional spare tactors, three on the front and three on the back. The tactor columns fall on the front, front-left, left, back-left, back, back-right, right, and front-right of the pilot that provides directional information in 45 degree increments (McGrath, 2004). In another USAARL study, 2008-12, experimenters used a TSAS belt that provided drift information to pilots via a belt worn around the waist that consisted of 8 electromagnetic tactors placed every 45 degrees (Curry, 2008).

There was some concern about the comfort and viability of wearing the TSAS during flight by the Air Warrior leadership. Both of the USAARL studies mentioned above, as part of the effort, surveyed all of the pilots at the end of the experiment about the comfort of the device. Only two pilots reported any issue with the TSAS, saying it was too constricting, but could be re-designed to be made more comfortable. Since pilots already wear vests while flying, instead of adding yet another vest or belt to be worn, which may indeed be cumbersome and uncomfortable, tactors could be incorporated into the existing vest already worn, as long as quality tactor signals could be ensured and the input still be detected by the pilots.

While comfort is certainly an important issue, the systems ability to affect workload and pilot situational awareness is perhaps of more concern. Both the USAARL studies mentioned above, as well as other Naval Aerospace Medical Research Lab (NAMRL and U.S. Air Force Research Lab (USAFRL) studies, show beyond doubt that the TSAS system, in any tested configuration, tactor type or array, reduces pilot workload and increases the situational awareness of pilots.

Researchers from Sungkyunkwan University in Korea and the University of Nevada have developed an in-

Function	Sub-Function	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7	Rank 8	Rank 9	Rank 10	Rank 11	Rank 12
Aircraft Takeoff	Perform Before Takeoff Checks	Status of Flight Inst.	Fuel Status	Power Lever	Crew Status	Status of MC	Radio Status	Infrared CM Status	Transponder Status	Chaff Dis. Status	Radar Jam Switch	Satellite Coverage	Armor Panel Status
	Perform Hover	Obstacle Location	Drift	% Torque	Altitude	Heading	Attitude	Trim	*****	*****	*****	*****	*****
	Establish Climb	Obstacle Location	% Torque	Airspeed	Rate of Climb	Heading	Altitude	Attitude	Trim	*****	*****	*****	*****
In-flight Operations	Control Flight Parameters	Airspeed	Altitude	Heading	% Torque	Time	Attitude	Trim	*****	*****	*****	*****	*****
	Perform Navigation	Obstacle Location	GPS Data	Heading	Map Information	Groundspeed	*****	*****	*****	*****	*****	*****	*****
Non-standard Events	React to Aircraft Malfunction	Emergency Procedures	Systems Status	Status of MC	*****	*****	*****	*****	*****	*****	*****	*****	*****
	Receive FRAGO	New LZ Location	RP Location	New Route	New Landing Heading	Wind Direction on LZ	Satellite Coverage	*****	*****	*****	*****	*****	*****
	React to Enemy Ground Fire	Threat Location	Obstacle Location	Alt Change EM	Chaff Dispensing	Head Change EM	Att Change EM	Torque Change EM	CMWS Warning	Speed Change EM	Location	Heading to ACP	*****
Land Aircraft	Perform Before Landing Checks	LZ Location	Crew Status	Radio Status	Tailwheel Light	Jamming Status	Chaff Dis. Status	Infrared CM Status	Parking Break	*****	*****	*****	*****
	Initiate Approach	Obstacle Location	Rate of Descent	Airspeed	Altitude	% Torque	Drift	Heading	Attitude	Trim	*****	*****	*****
	Land	Obstacle Location	Rate of Closure	Wind Direction	Altitude	Attitude	Heading	Door Status	Status of Unloading	*****	*****	*****	*****
Systems	Monitor Aircraft Systems	Rotor RPM	Status of MC	Eng 1,2 RPM	Fuel Quantity	Status of Advisory Panel	Fuel Consumption Rate	*****	*****	*****	*****	*****	*****
	Conduct Communications	Internal	Serial	Ground CDR	AVN CMD	ATC	*****	*****	*****	*****	*****	*****	*****
Resource-P	Overall	Auditory	Visual	Cognitive	Fine Motor	Speech	*****	*****	*****	*****	*****	*****	*****
	Auditory	Internal Radio	Comms w/ Serial	AVN CMD Net	Aircraft Noise	Comms w/ Ground	Comms w/ ATC	CMWS Tones	*****	*****	*****	*****	*****
	Visual	Friendly Aircraft	Gauges	Displays	Indicator Lights	Ground Obstacles	Objective Area / LZ	Ground Forces	*****	*****	*****	*****	*****
	Cognitive	Planning	Map Reading	Systems Decisions	Calculations	GPS / Course Tracking	*****	*****	*****	*****	*****	*****	*****
	Fine Motor	Toggling	Adjusting Cyclic	Writing	Adjusting Collective	Adjusting Pedals	*****	*****	*****	*****	*****	*****	*****
	Speech	Internal	Serial	ATC	Ground	*****	*****	*****	*****	*****	*****	*****	*****
Resource-CP	Overall	Cognitive	Auditory	Visual	Speech	Fine Motor	*****	*****	*****	*****	*****	*****	*****
	Auditory	Internal Radio	Comms w/ Serial	Aircraft Noise	AVN CMD Net	Comms w/ ATC	Comms w/ Ground	CMWS Tones	*****	*****	*****	*****	*****
	Visual	Gauges	Friendly Aircraft	Ground Obstacles	Displays	Objective Area / LZ	Indicator Lights	Ground Forces	*****	*****	*****	*****	*****
	Cognitive	Planning	Systems Decisions	GPS / Course Tracking	Map Reading	Calculations	*****	*****	*****	*****	*****	*****	*****
	Fine Motor	Adjusting Cyclic	Adjusting Collective	Toggling	Adjusting Pedals	Writing	*****	*****	*****	*****	*****	*****	*****
	Speech	Internal	Serial	ATC	Ground	*****	*****	*****	*****	*****	*****	*****	*****

Figure 4: UH-60 Survey Results

Overcoming Information Overload

Function	Sub-Function	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7	Rank 8	Rank 9	Rank 10	Rank 11	Rank 12	Rank 13	Rank 14
Aircraft Take off	Perform Before Takeoff Checks*	Power Lever	Flight Instruments	Status of MC	Weapons Status	UFD / EUFD Cautions	Status of A/S Button	Radio Status	ASE Status	Fuel Status	Tailwheel Status	Transponder Status	GND ORIDE Button	Satellite Coverage	Parking Brake Status
	Perform Hover*	Obstacle Location	% Torque	Drift	Altitude	Attitude	Heading	Trim	*****	*****	*****	*****	*****	*****	*****
	Establish Climb*	% Torque	Obstacle Location	Airspeed	Altitude	Rate of Climb	Altitude	Trim	Heading	*****	*****	*****	*****	*****	*****
In-flight Operations	Control Flight Parameters*	Attitude	% Torque	Airspeed	Trim	Altitude	Heading	*****	*****	*****	*****	*****	*****	*****	*****
	Perform Navigation*	Obstacle Location	TSD Route Info	Heading	Fuel Consump. Rate	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
	In-flight CP G Tasks*	Weapons Systems Status	Sight Systems Status	Camera / Video Status	Recorder Status	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
Non-standard Events	React to Aircraft Malfunction*	ENG 1 Power	Emergency Procedures	Aircraft Systems	Status of MC	UFD / EUFD Cautions	*****	*****	*****	*****	*****	*****	*****	*****	*****
	Receive FRAGO*	Target Location	Enemy Situation	New Route	Waypoint Location	Satellite Coverage	*****	*****	*****	*****	*****	*****	*****	*****	*****
	Engage Enemy with 30mm*	Friendly Location	Enemy Location	Obstacle Location	Range to Target	Weapons Status	Impact Location	Attack Pattern	Symbolology Alignment	Angle of Attack	*****	*****	*****	*****	*****
Land Aircraft	Perform Before Landing Checks*	Weapons Status	Airfield Location	Parking Brake Status	Tailwheel Status	Status of A/S Button	Radio Status	GND ORIDE Button	ASE Status	*****	*****	*****	*****	*****	*****
	Initiate Approach*	Obstacle Location	Attitude	% Torque	Rate of Descent	Airspeed	Altitude	Heading	Drift	Trim	*****	*****	*****	*****	*****
	Land*	Obstacle Location	% Torque	Wind Direction	Rate of Closure	Altitude	Airspeed	Drift	Altitude	Heading	Trim	*****	*****	*****	*****
Systems	Monitor Aircraft Systems*	Status of MC	Rotor RPM	Eng 1, 2 RPM	Eng 1, 2 Gas Temp	Fuel Quantity	UFD / EUFD Cautions	Eng 1, 2 Gas Gen Speed	Aircraft Endurance	Fuel Flow	*****	*****	*****	*****	*****
	Conduct Communications*	Internal	Wingman	Ground CDR	AVN CMD	ATC	*****	*****	*****	*****	*****	*****	*****	*****	*****
Resource-P	Overall	Visual	Cognitive	Auditory	Speech	Fine Motor	*****	*****	*****	*****	*****	*****	*****	*****	*****
	Auditory	Internal Radio	Comms w/ Wingman	Comms w/ Ground	Aircraft Noise	Comms w/ ATC	Audio Tones	AVN CMD Net	*****	*****	*****	*****	*****	*****	*****
	Visual	General Scanning	Obstacle Location	Ground Forces	Sight Scanning	Friendly Aircraft	Displays	Indicator Lights	Gauges	*****	*****	*****	*****	*****	*****
	Cognitive	Processing Input	Display Info	Systems Decisions	Attack Parameters	Planning	Following Route	Calculations	*****	*****	*****	*****	*****	*****	*****
	Fine Motor	Adjusting Cyclic	Adjusting Collective	Adjusting Pedals	Toggling	Tracking Targets w/ Sight	*****	*****	*****	*****	*****	*****	*****	*****	*****
	Speech	Internal	Wingman	ATC	Ground	AVN CMD Net	*****	*****	*****	*****	*****	*****	*****	*****	*****
Resource-CPG	Overall	Auditory	Cognitive	Speech	Fine Motor	Visual	*****	*****	*****	*****	*****	*****	*****	*****	*****
	Auditory	Comms w/ Ground	Internal Radio	Comms w/ Wingman	AVN CMD Net	Comms w/ ATC	Audio Tones	Aircraft Noise	*****	*****	*****	*****	*****	*****	*****
	Visual	Sight Scanning	General Scanning	Obstacle Location	Displays	Ground Forces	Friendly Aircraft	Indicator Lights	Gauges	*****	*****	*****	*****	*****	*****
	Cognitive	Planning	Processing Input	Display Info	Following Route	System Decisions	Attack Parameters	Calculations	*****	*****	*****	*****	*****	*****	*****
	Fine Motor	Toggling	Adjusting Cyclic	Tracking Targets w/ Sight	Adjusting Collective	Adjusting Pedals	*****	*****	*****	*****	*****	*****	*****	*****	*****
	Speech	Internal	Wingman	Ground	AVN CMD Net	ATC	*****	*****	*****	*****	*****	*****	*****	*****	*****

Figure 5: AH-64D Survey Results

novative tactile display based on soft actuator technology. This type of tactile display overcomes the potential rigidity and bulkiness of the tactor centered TSAS technology, and is soft and flexible enough to conform to almost any part of the human body, such as the fingertip, palm, hand (in a glove shaped configuration), or the arm (Koo, 2008). The technology conveys information to the wearer, the pilot in our case, when electrodes induce a voltage across the actuator film, which is approximately 210 micrometers thin. The voltage causes the films to compress down and expand outward, thereby exerting pressure on the wearer's skin (Koo, 2008). Additional advantages of this technology include simplicity of electronics, efficient power usage, cost effectiveness, and easy fabrication. This technology has the most potential of any of those discussed here based due to its reduced profile and close connection to the wearer's skin, making sensing the tactile signals much easier to detect, and minimizing the amount of necessary equipment.

Originally designed to mitigate the number of crashes on the road caused by roadway departures, drowsy driving, and forward and intersection collisions, the Haptic seat was created in order to provide drivers with tactile feedback to avoid such eventualities (Stanley, 2008). A haptic signal, or seat vibration, was designed to interface with drivers when and if lane or roadway departures occurred (Stanley, 2008). While the study referenced here demonstrated that the use of psychophysical interfaces is indeed warranted in design alternatives, the use of a haptic seat in helicopters may be problematic. The inherent vibration of the helicopter may prevent quality tactor-pilot interface, which is a key capability in relation to tactile interfaces.

Another cockpit display system that gives tactile feedback to pilots uses a 6x4 pin array device that is mounted on the cyclic control stick that provides pilots with an altitude tracking cue. The device conveys path angle error, the error angle between the current flight path and the interception path to the target trajectory, to the pilot through the tactile display in order to keep the appropriate vertical trajectory (Nojima, 2005). The advantage of this system is that it does not require the pilot to wear any additional gear,

which given the tight quarters of a cockpit and the significant amount of equipment already worn by the pilots, is a nice feature. The major drawback, however, is that the cyclic control stick already has a lot of "stuff" on it, buttons, triggers, toggles, etc..., and the addition of more buttonology could potentially be a hindrance to pilot performance.

Researchers at the USAFRL developed a tactile feedback system consisting of a modified control stick that provides force reflected feedback to guide pilots onto the correct heading. When the aircraft deviates from the desired course, the force reflecting feedback makes it physically easier for the pilot to input commands toward the correct heading, and physically more difficult to input commands away from the correct route. Pilot evaluations of this system showed a significant reduction in heading deviation when compared to no force reflecting feedback was provided (Spirkovska, 2004). This technology could be used by helicopter pilots, when flying an air assault mission in which they must maintain the correct heading, to keep them moving in the proper direction in order to meet their time-on-target.

Rather than using tactors to convey information to pilots, in this case the aircraft's angle of attack, NASA's Dryden Flight Research Center developed a Pressure Cuff that utilized a number of inflatable, pneumatic bladders, held to the pilots arm by straps (Spirkovska, 2004). The number and location of activated bladders is directly related to the pilot's angle of attack. While this technology was developed with fixed-wing fighter pilots in mind, certainly Apache pilots could benefit from receiving information in alternate ways concerning their angle of attack against enemy targets, or the technology could be modified to provide alternate information to pilots.

Researchers at Pohang University of Science and Technology in Korea have been evaluating wearable tactile interfaces for motion training using a metaphor called "Ghosts", which is a transparent rendering of the trainer's motion as seen from the first person point-of-view. The "ghostly master", initially coincident with the subject's body, guides the motion, through tactor interface, and this is seen from the trainee's viewpoint as the trainer's limbs moving

out of his body (Spirkovska, 2004). The subject is then to follow by moving his own limbs to match the motion of the trainer's. Along with the concept, researchers developed a tactile garment consisting of an array of 60 vibratory motors worn in the torso region arranged in 5 circular rings with 12 motors spaced at 30 degrees and controlled by a Pentium PC. This was originally designed to teach dance moves, but could also be used to teach or remind pilots of emergency procedures by directing pilot motion towards the correct instrument panel or control (Spirkovska, 2004).

Not only can tactile technologies reduce visual workload by providing flight data via the haptic sense, but they also can impact auditory resource allocation. The difficulty for pilot and copilots in the audio domain is listening to multiple radios on multiple different nets. In order to simultaneously listen to multiple nets, pilots have the radios adjusted to different volumes and must rely upon voice recognition to determine who is talking on what net. An application of tactile technologies to address this problem is the idea of using tactile melodies and 3D audio. Tactile melodies are different vibration rhythms that can be easily recognized with little cognitive processing (Castle, 2002). Instead of relying solely on the auditory sense to differentiate between radio nets / calls, pilots could receive a corresponding tactile vibration that would tell them what net the radio traffic is coming over, and hopefully ease the burden on the auditory sense. This is the equivalent of tactile ring tones for different radio nets. Another idea that should reduce auditory workload on pilots is the use of 3D audio. Three dimensional audio is a technology, that on a headset, recreates directional sound, and researchers from the U.S. Air Force Research Laboratory are finding that it is extremely important to spatialize sounds in order for pilots to distinguish between them (Adams, 2006). 3D audio (with head tracker) can be used to more effectively distinguish between radio calls by localizing the different nets in different places, to give direction information concerning enemy radar locations, or to give navigation cues to pilots by getting heading from the direction of the sound in the headset, and a distance from a speech based cue. The further you are from the way-

point or destination, you would hear the distance in a shout, closer still and you would hear the remaining distance in a normal voice, and when "close" to the waypoint, you would hear the distance in a whisper (Adams, 2006). This audio cueing waypoint navigation would certainly reduce the visual workload on the pilot, but care should be taken putting a larger auditory workload on a resource that many pilots already feel overloaded in.

6 Alternative HUD Symbology Layout Survey

This part of the second study objective involved researching possible alternative HUD symbology layout and design. Ideas presented here include taking advantage of pilot habit patterns, creating optimal HUD symbologies or evaluating current ones using a concept called Layout Appropriateness (LA), and a synopsis of the Brown-Out Landing Display (BOLD) symbology design.

The first idea for alternate HUD symbology involves the concept of learned habit patterns. A habit, of course, is a behavior that is repeated so often that it becomes automatic. Pilots, like any other human being, also fall into these learned habit patterns. Specifically, they check flight parameters, instrumentation, etc... in an specific pattern, based on situation or cockpit layout. In light of this idea of learned habit patterns, it would seem appropriate for the HUD symbology to be oriented as close as possible to the original cockpit gauges, both in relative location and appearance. Currently, this is not the case for any of the Army rotary-wing cockpit gauge layout and their corresponding HUD symbology. Similar layouts would enhance a pilots ability to sort through and process information and make the switch from day to night flying that much easier. Although it's not clear at this point how much of a benefit this would be to pilots, as no experiment has been conducted, I would argue that they could be significant.

Let us consider an example from scenario one described in section 3, and suppose we are in straight

and level flight ingressing to the objective. During this portion of the mission, survey results tell us that the flight parameters pilots are most concerned about are airspeed, altitude (barometric and radar), heading, and % torque, and are checked in that order. Now let us consider figure 6 below. The figure on the left is the Primary Flight Display (PFD) found in the UH-60M, and the one on the right is a HUD prototype provided to the author by PM Air Warrior.

Ignoring the arrows for the moment, let us look at the differences between the two. We notice that heading, airspeed, engine readouts, and the master caution / warning information are all located in different places, with different formatting. The arrows indicate the order in which the flight parameters are checked, again based on the survey results, and one can clearly see the different patterns. The PFD is checked in a kind of zig-zag pattern, while the HUD is inspected in a counter-clockwise circular motion. With this simple example and diagram, we can see that HUD symbology portrayed here does not take advantage of previously learned habit patterns, thereby forcing pilots to change their own internal standard operating procedures when switching from day to night flying. The same layout for the PFD and HUD would enable pilots to make a safer, smoother transition between day and night flying, with the potential to increase SA and reduce workload.

The second idea to be presented here is that of Layout Appropriateness, developed by Dr. Andrew Sears in 1993. In a nutshell, Layout Appropriateness is a metric by which designers can determine the best way to organize a certain number of “widgets” in a user interface based on task descriptions, cost, and frequency of use, within a specified grid sized interface (Sears, 1993). It can be used in the creation of a new interface, as LA can find the optimal layout, or it can be used in comparing alternative designs against the optimal. The use of LA requires four things: a set of widgets to be used in the interface (in terms of this study, HUD symbology icons), the sequence of actions that users perform that represent one way of accomplishing a task (for example, checking flight parameters, what are all the different ways a pilot can accomplish this task?), a cost assigned to each task,

and how frequently each sequence is used (how often a pilot checks flight parameters in a certain way). The cost here can be chosen to represent many different things. It could be the time it takes a user to complete a movement, the distance a user moves when executing a task, the number of eye fixations required to extract information, the number of changes in direction, or really anything that the designer thinks is relevant (Sears, 1993). LA then uses a branch and bound algorithm to search for the optimal layout and its associated cost by minimizing the average cost of all sequences based on frequency of use. Constraints can be added to the model if certain widgets must be located in a certain position or adjacent to another widget. The appropriateness, or cost of an alternative design is computed by weighing the cost of each sequence of actions by how frequently the sequence is performed.

Mathematically, it looks like:

$$cost = \sum_{all\ transitions} [Frequency * Cost]$$

One can then quantitatively compare alternative designs against each other using the optimal layout and the following formula:

$$LA = 100 * \left[\frac{cost\ of\ LA\ optimal\ layout}{cost\ of\ alternate\ layout} \right]$$

Clearly, the LA optimal design receives a LA score of 100, and alternative designs a lesser one.

While this is a viable technique to create new HUD symbology layouts or compare existing alternative ones, the difficulty, in the context of this study, would lie in determining the frequency of sequences that pilots use to accomplish a task throughout the course of a mission. Approximate frequencies could be obtained from either pilot surveys, human in the loop simulations, or some kind of discrete event computer simulation similar to IMPRINT. With these numbers in hand, finding the optimal layout using LA is relatively straightforward.

JXT Applications, Inc. recently completed a Small Business Innovation Research (SBIR) (Phase 1)

Overcoming Information Overload

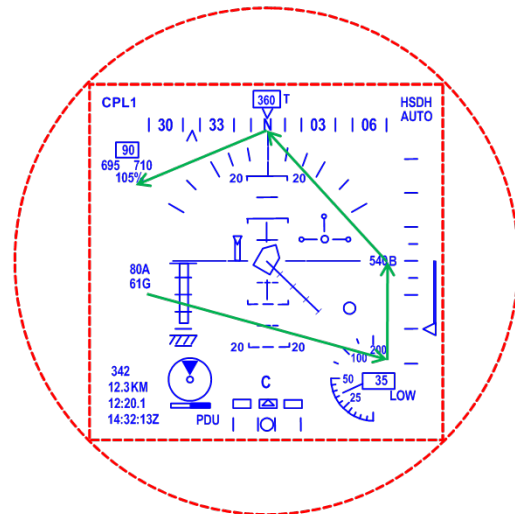
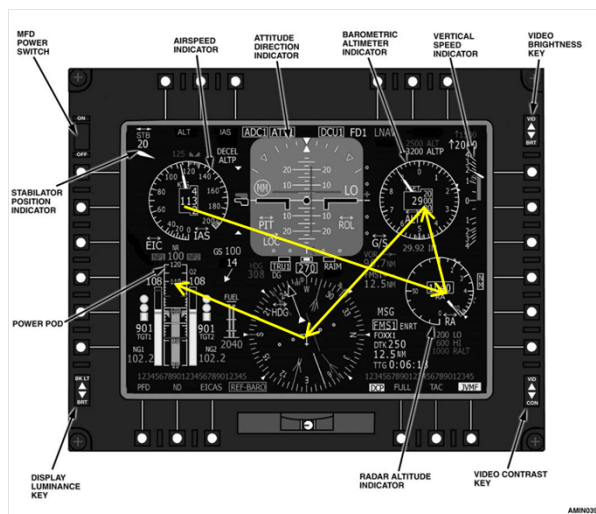


Figure 6: UH-60M PFD & HUD Prototype

project for the Naval Air Warfare Center - Aircraft Division, in which they proposed a new helmet mounted display symbology for rotary-wing aircraft flying in degraded visual environments (DVE), called the Brown-Out Landing Display symbology set. I offer here a brief synopsis of the BOLD symbology and comparison to the current HUD symbology as found in the AN/AVS-7.

Below in figure 7 are shown the complete symbology sets for the BOLD and AVS-7 HUD.

We notice that the AVS-7 has a 120 degree range, 10 degree tick separation, with a central vertical reference carrot that gives the current heading, while the BOLD symbology set has a smaller 60 degree range, 15 degree tick marks, with a small vertical current heading index, since greater precision during landing is not usually necessary. The torque reading is identical in each of the symbology sets. The Master Caution Indicator is located in the center bottom on the AVS-7, while on the BOLD set, is located in the center top. For the radar altimeter, the AVS-7 displays a boxed digital readout above ground level altitude, a “R” (for radar) in the center right of the display area, and a vertical scale and pointer to the right of the digital readout. The BOLD symbology set uses an angular, semicircular (6-12 o’clock) analog logarithmic scale on the right side of the display that provides rate cues and consequently greater precision near ground and more easily monitored using peripheral vision. The vertical speed indicator on the AVS-7 is an angular linear scale and pointer in the center left of the display, while the BOLD set uses an analog, semicircular linear scale with non-linear scaling and digital sink rate display, with a carrot indicating vertical acceleration. Both the BOLD symbology set and the AVS-7 have de-clutter mode options in order to reduce the amount of symbology displayed to the pilot at any time. The color scheme of the AVS-7 is monochrome green, while the BOLD symbology set color scheme is yet to be determined. Designers at JXT Applications, Inc. have created a Background Generation Tool that enables testing of symbology colors against different backgrounds. The research, however, is still ongoing, but designers anticipate that black and white symbologies will be most effective;

black against a lighter background, white against a darker one (Shaw, 2008).

We notice a common theme throughout the descriptions of the BOLD symbology set, that is, fewer lit pixels and an overall cleaner looking, more intuitive display. While the BOLD symbology was designed for use in a specific situation, landing in degraded visual environments, I believe that future HUD symbology sets can use some of the BOLD design elements: the use of fewer lit pixels to increase pilot visual acuity during night flying, and the use of more intuitive displays.

7 IMPRINT Simulation Configuration

The simulation output that we were most concerned about in this study was that of workload. Workload demand theory, which is used in IMPRINT, is based on the idea that every task that a pilot / copilot performs requires a resource to accomplish it, and each task is composed of demands in one or more of the resource channels (auditory, visual, cognitive, fine motor, or speech) (McCracken, 1984). IMPRINT is used to assign workload values to each specified task the corresponding amount of demand by resource channel, and does so by a listing of scale values and textual descriptors. The scale ranges from 0.0 to 7.0 with associated descriptors which increase in value with a corresponding heightened level of information processing in the human brain (Wojciechowski, 2006). When the simulation executes, each resource channel is summed for all tasks being done, and this total value is the workload in that resource at that particular instant in time (Wojciechowski, 2006), and all of the individual resources sum to the overall workload total. The scale and associated textual descriptors that IMPRINT uses are given in Appendix H.

There were a total of four models built in IMPRINT for comparison purposes. The first UH-60 simulation is modeled after the current UH-60A/L cockpit, and the second UH-60 simulation is exactly the same as

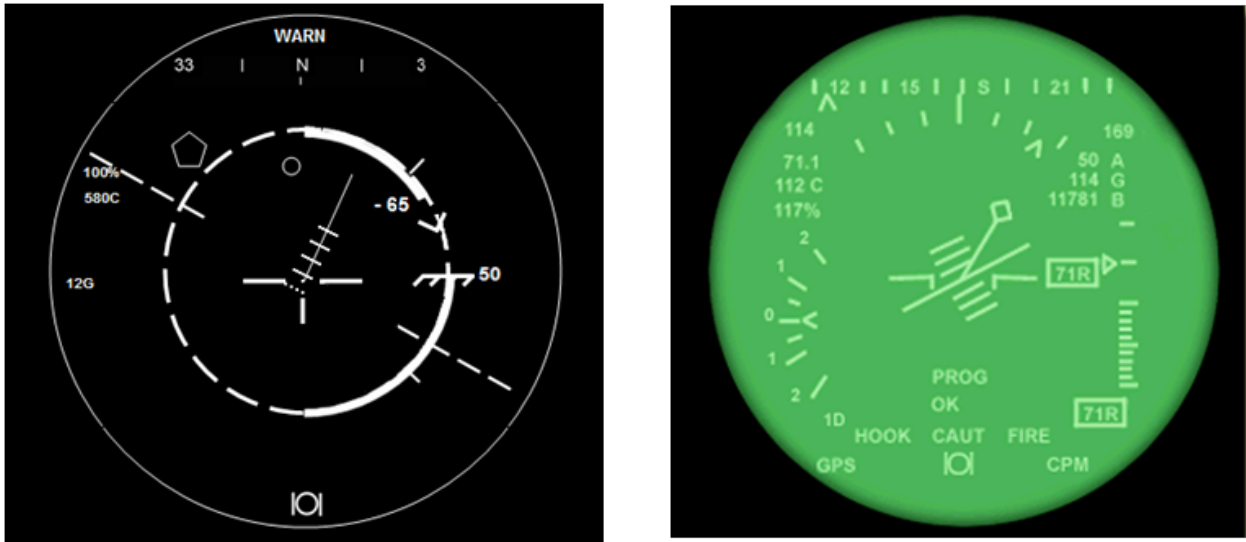


Figure 7: BOLD and AN/AVS-7 Symbolology (Shaw, 2008)

the first but is modified to contain tactile technologies, 3D audio, and voice activated internal communication system.

Specifically:

- TSAS vest that provides:
 - Drift, attitude, airspeed, and altitude information to pilots while conducting hover and landing operations.
 - Threat location for Common Missile Warning System (CMWS).
 - Objective (target) and airfield location.
- Soft Actuator technology that provides:
 - Trim and heading information while in flight.
- 3D Audio with head tracking.
- Voice activated internal communication system (ICS) (UH-60 only).

The first Apache simulation is modeled after the current AH-64D Longbow cockpit, and the second contains the same tactile technologies and 3D audio as the UH-60 model (AH-64D already utilizes voice activated ICS). Both the Blackhawk and Apache models used in IMPRINT were taken directly from the results of the functional analysis of both missions. All tasks that appear in the functional analysis were assigned approximate times to complete task execution, and an associated workload in whichever resource that the task demanded. This information is provided in Appendices I, J (Blackhawk) and K, L (Apache).

Model validation is certainly an important part of any non-human-in-the-loop simulation experiment. While subject matter experts were involved in validating the above mentioned IMPRINT models, and the models were created to reflect as accurately as possible the actual task performance of the pilot and copilot, the primary focus of this study is to determine the differences between the current and alternate cockpit layouts for both aircraft. Whatever errors or inaccuracies that may be present in the current cockpit design, are also present in the alternate,

and in effect cancel each other leaving only the delta, or change, between the two to investigate.

8 Simulation Results

A total of 30 runs were done on both aircraft's for both the current and alternate cockpit designs. The data collected was the average of the overall workload for each run, and the average workload by resource, i.e., auditory, visual, cognitive, fine motor, speech, and tactile (only in the alternate design) for each separate run. Data for the pilot and copilot were captured in each of the models. Normal plots of the overall and resource average workloads were then generated in Minitab in order to ensure that our assumptions of normality were not violated, so that we could proceed with our data analysis by employing a Two-Sample T-test (assuming unequal variances) comparing the mean of the average overall and resource workloads from the current and alternate cockpits to each other.

8.1 Blackhawk

An example from one simulation run is shown in figure 8 below to give the reader a visual representation of the different overall workloads experienced throughout the course of the mission by the pilot in the current cockpit versus the alternate. While clearly the total workload experienced by the pilot in the alternate cockpit is lower on average, it seems to have a greater variance than the current. That is, the workload, while lower, has a greater spread about the mean. However, when we test for statistically significant differences between the two sample variances, we find none. The rationale behind conducting this test was the result of a concern about whether workload that was constant, but higher, being more desirable than a workload that is on the average lower but with much greater variance, and its possible effect on pilot performance in the cockpit.

Figure 9 depicts four pie charts that depict the resource breakdown for the pilot and copilot in the current and alternate cockpit configurations. The top

two charts represent the current cockpit for the pilot and copilot, and a quick glance tells us that the visual and cognitive resources account for the largest percentage, approximately 80%, of the overall workload. This would indicate that new technologies could have the largest impact on reducing and shifting workload if we target these two resources. The bottom two pie charts illustrate the alternate cockpit configuration for both pilot and copilot which includes the tactile technologies, 3D audio, and voice activated ICS. We notice that the visual workload has been reduced, and that this workload has been shifted onto the tactile channel, while the cognitive resource has remained approximately the same, with perhaps a small increase in the percentage of total workload.

Next we take a look at the average workload values for the overall and the auditory, visual, and cognitive resources for both the pilot and copilot. Figure 10 are boxplots of the data that give us an idea of the workload differences between the current and alternate cockpit designs.

The boxplots alone seem to indicate significant differences between the mean overall workload and that of the individual resources as well. The alternate cockpit design seems to significantly reduce the workload in all categories. The following table gives the percent reduction in workload for the pilot and copilot for the overall and individual resources when using the alternate cockpit:

	Overall	Visual	Cognitive	Auditory
Pilot	12%	32%	10%	28%
Copilot	16%	38%	9%	24%

We can also look at the percent of the overall reduction provided by the new technologies that we added to the alternate cockpit design. For the copilot, the 3D audio accounted for approximately 24% of the total 16% overall reduction in workload, while accounting for nearly 28% of the 12% reduction for the pilot. The tactile display technologies accounted for 47% of the 16% reduction for the copilot, and approximately 42% of the 12% reduction for the pilot.

To test for statistically significant differences between the different cockpit designs, we compare the current

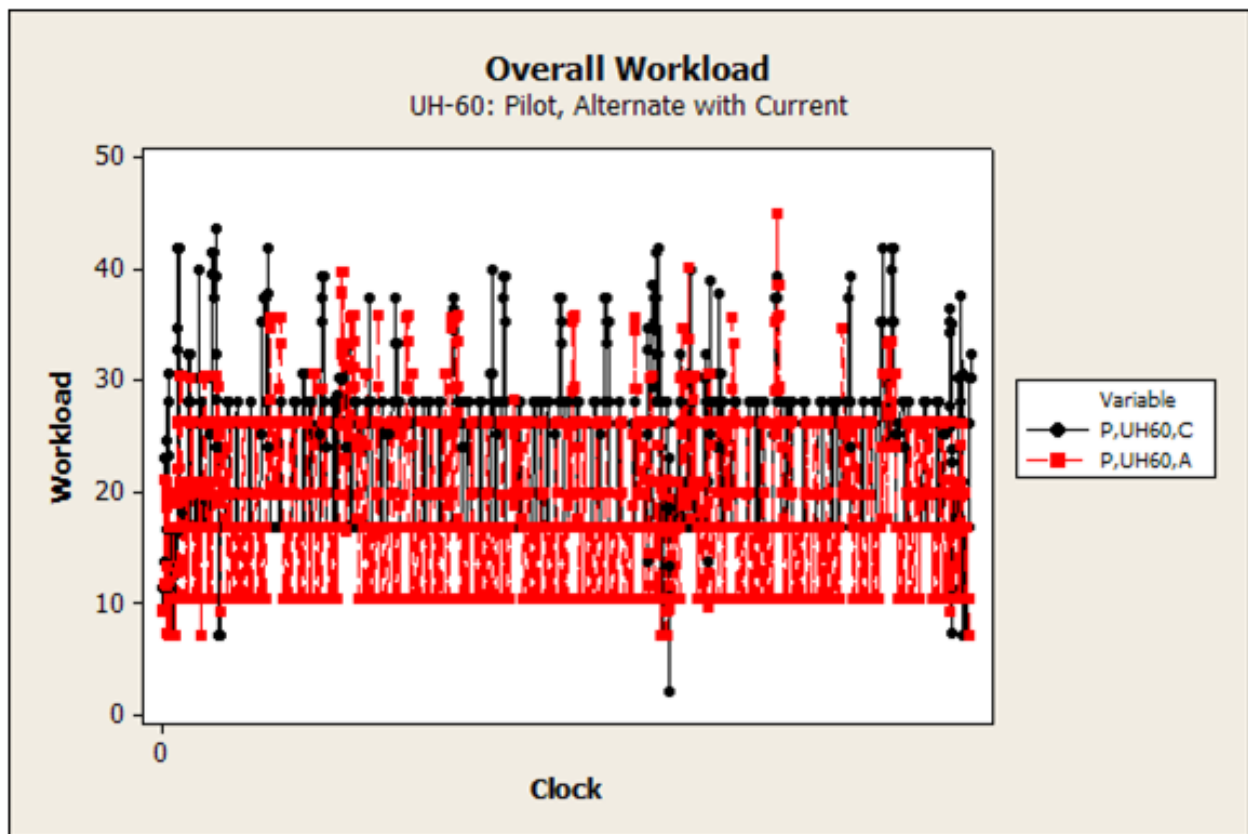


Figure 8: UH-60 Current vs. Alternate Pilot Workload

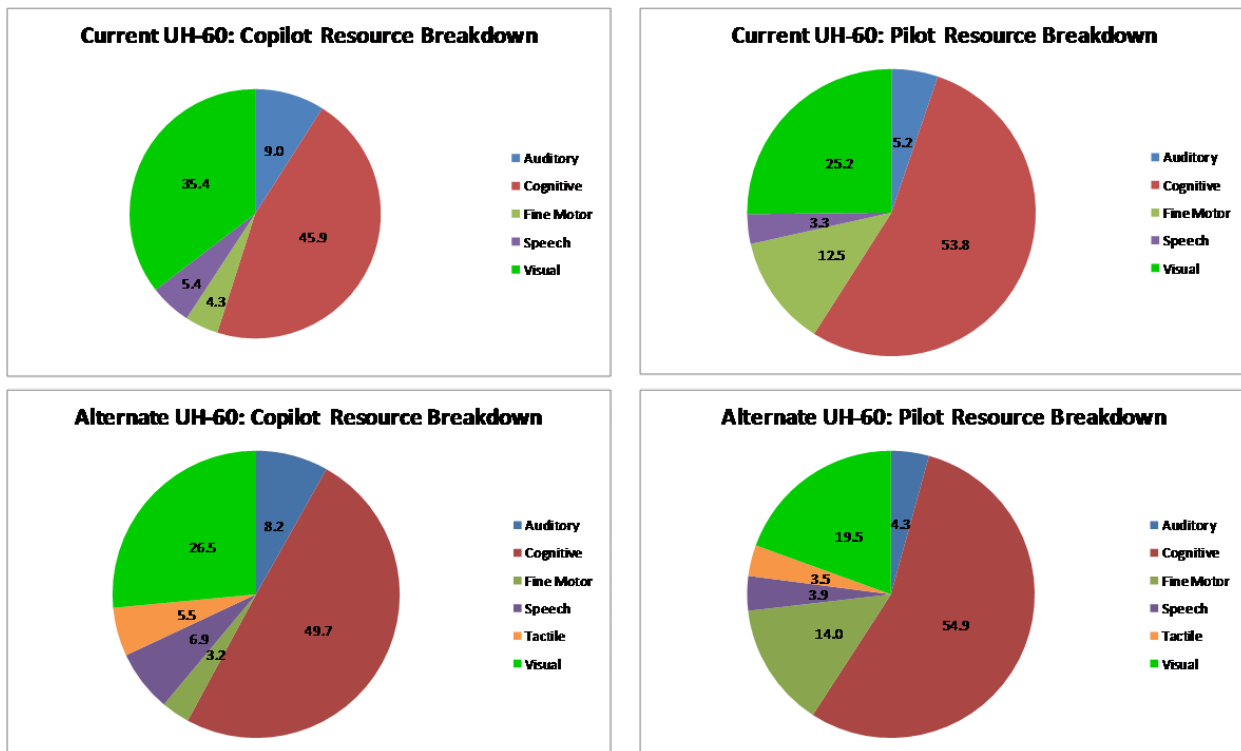


Figure 9: UH-60 Resource Breakdown

Overcoming Information Overload

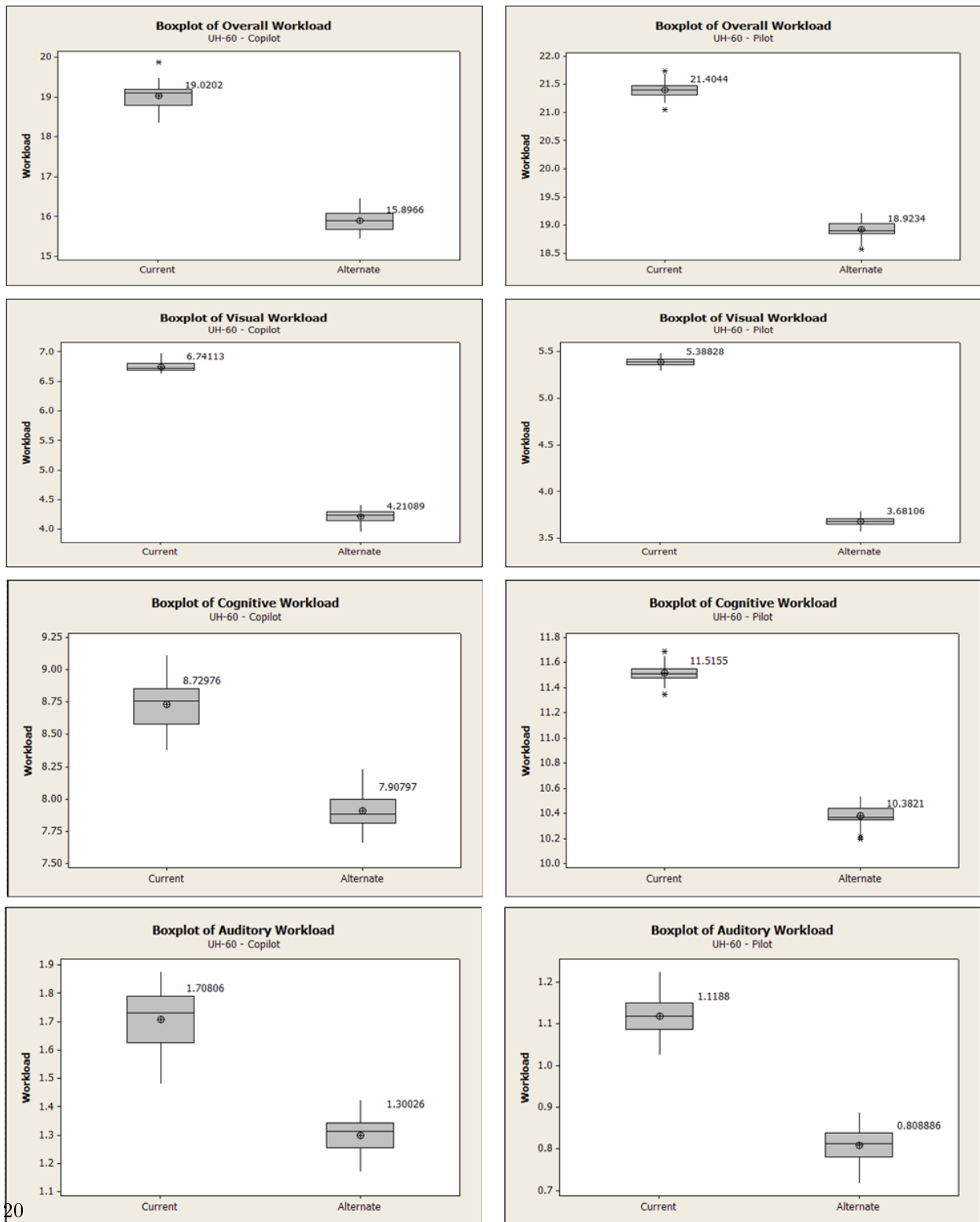


Figure 10: UH-60 Resource Boxplots

and alternate cockpit workloads using a Two-sample T-test, and after having done so for the overall and each of the channel workloads, we conclude that the alternate cockpit produces statistically significant differences for the overall workload as well as for the auditory, visual, cognitive, speech, and fine motor resources. All tests were conducted at a significance level of $\alpha = 0.05$, and reported p-values of < 0.05 , with no violation of our assumption of normality.

8.2 Apache

The analysis of the Apache scenario is exactly the same as the one conducted for the Blackhawk. As before, an example from one simulation run from the different cockpits is shown in figure 11. While the average workload of the alternate seems to be lower, the variances of the two cockpits appear quite similar, so there is no question about the effects of a workload variance that differs significantly and its effect on pilot performance.

The top two charts in figure 12 below represent the current cockpit for the pilot and copilot, and a cursory look tells us that the visual and cognitive resources account for the largest percentage, approximately 85%, of the overall workload. Again, this would indicate that new technologies could have the largest impact on reducing and shifting workload if we target these two resources. The bottom two pie charts illustrate the alternate cockpit configuration for both pilot and copilot which includes the tactile technologies and 3D audio. We again notice that the visual workload has been reduced, and that this workload has been shifted onto the tactile channel, while the cognitive resource has remained approximately the same, with perhaps a small increase in the percentage of total workload.

Figure 13 are the boxplots of the data that give us an idea of the differences between the current and alternate cockpit designs.

The boxplots seem to indicate significant differences between the mean overall workload and that of the individual resources as well. The alternate cockpit design seems to significantly reduce the workload in

all categories. The following table gives the percent reduction in workload for the pilot and copilot for the overall and individual resources when using the alternate cockpit:

	Overall	Visual	Cognitive	Auditory
Pilot	6%	9%	3%	30%
Copilot	10%	16%	6%	30%

As in the UH-60 analysis, we can also look at the percent of the overall reduction provided by the new technologies that we added to the alternate cockpit design. For the copilot and pilot, the 3D audio accounted for approximately 30% of the total 10% overall reduction in workload for the copilot, and of the 6% reduction for the pilot. The tactile display technologies accounted for 22% of the 10% reduction for the copilot, and approximately 12% of the 6% reduction for the pilot.

To test for statistically significant differences between the two cockpits, we again compare the current and alternate cockpit workloads using a Two-sample T-test, and after having done so for the overall and each of the channel workloads, we conclude that the alternate cockpit produces statistically significant differences for the overall workload as well as for the auditory, visual, and cognitive resources. Each test reported p-values of < 0.05 . We find, however, no difference between the resource workloads of speech and fine motor in the two cockpits, as p-values were greater than 0.05, which is not surprising since none of the new technologies that were introduced targeted these resources. All tests were conducted at a significance level of $\alpha = 0.05$.

9 Recommendations / Conclusions

The overall workload on pilot and copilots, especially during bad weather, reacting to aircraft malfunctions, or receiving incoming fire from the enemy, is significant. In short, the purpose of this study has been to identify what pieces of information are important to pilots at different times, especially during a

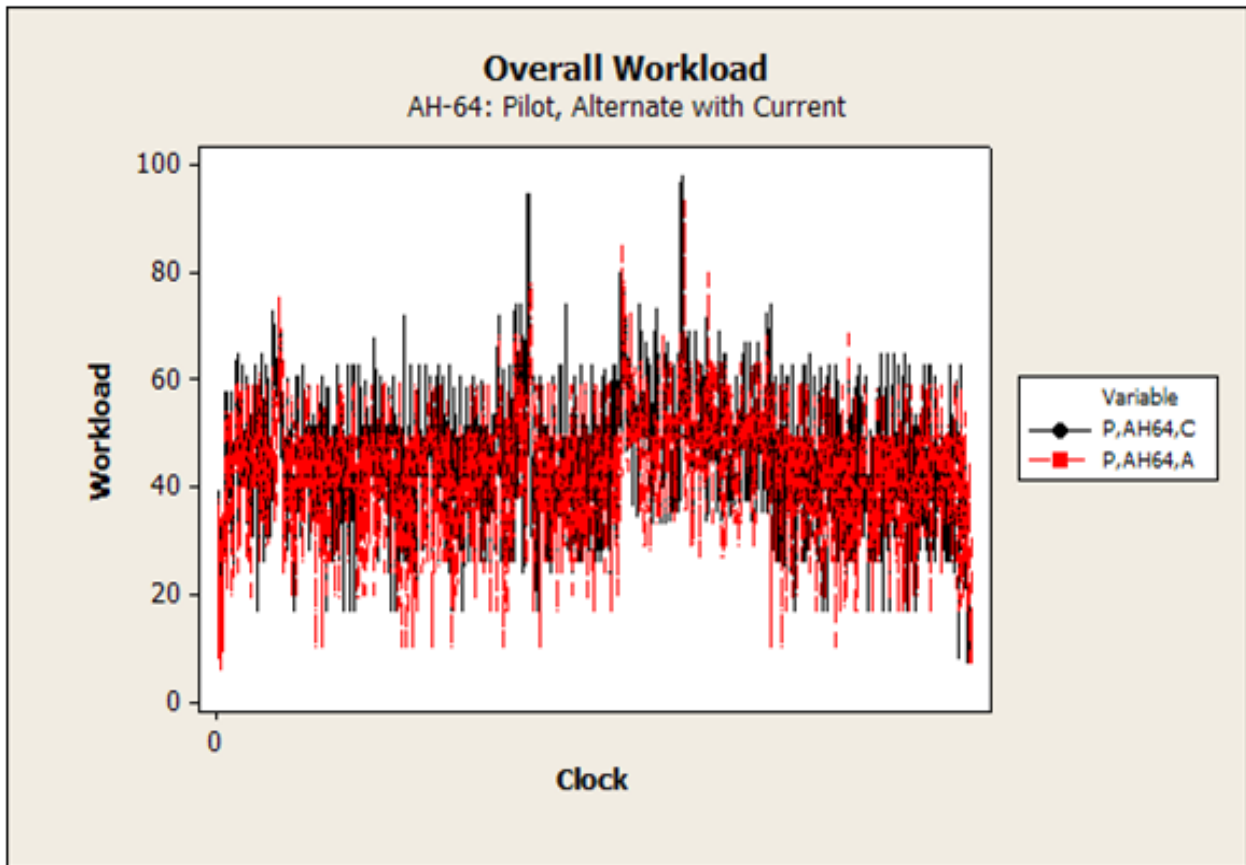


Figure 11: AH-64D Current vs. Alternate Pilot Workload

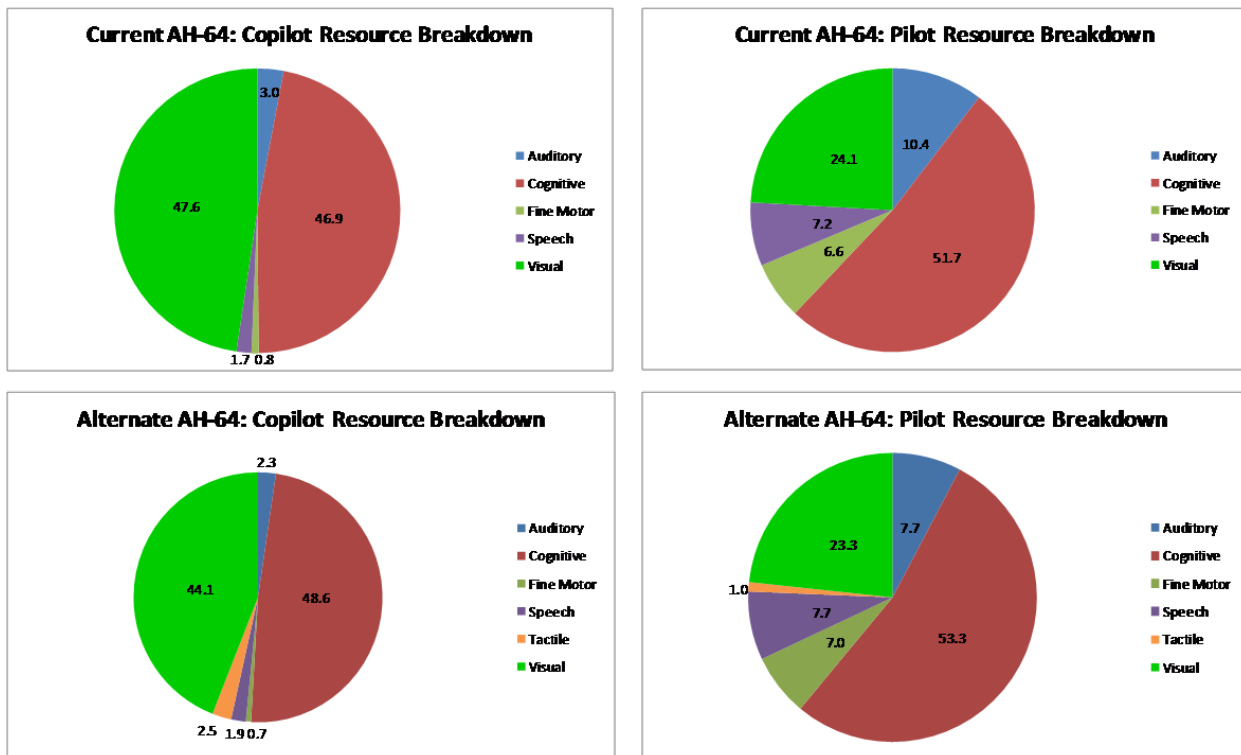


Figure 12: AH-64D Resource Breakdown

Overcoming Information Overload

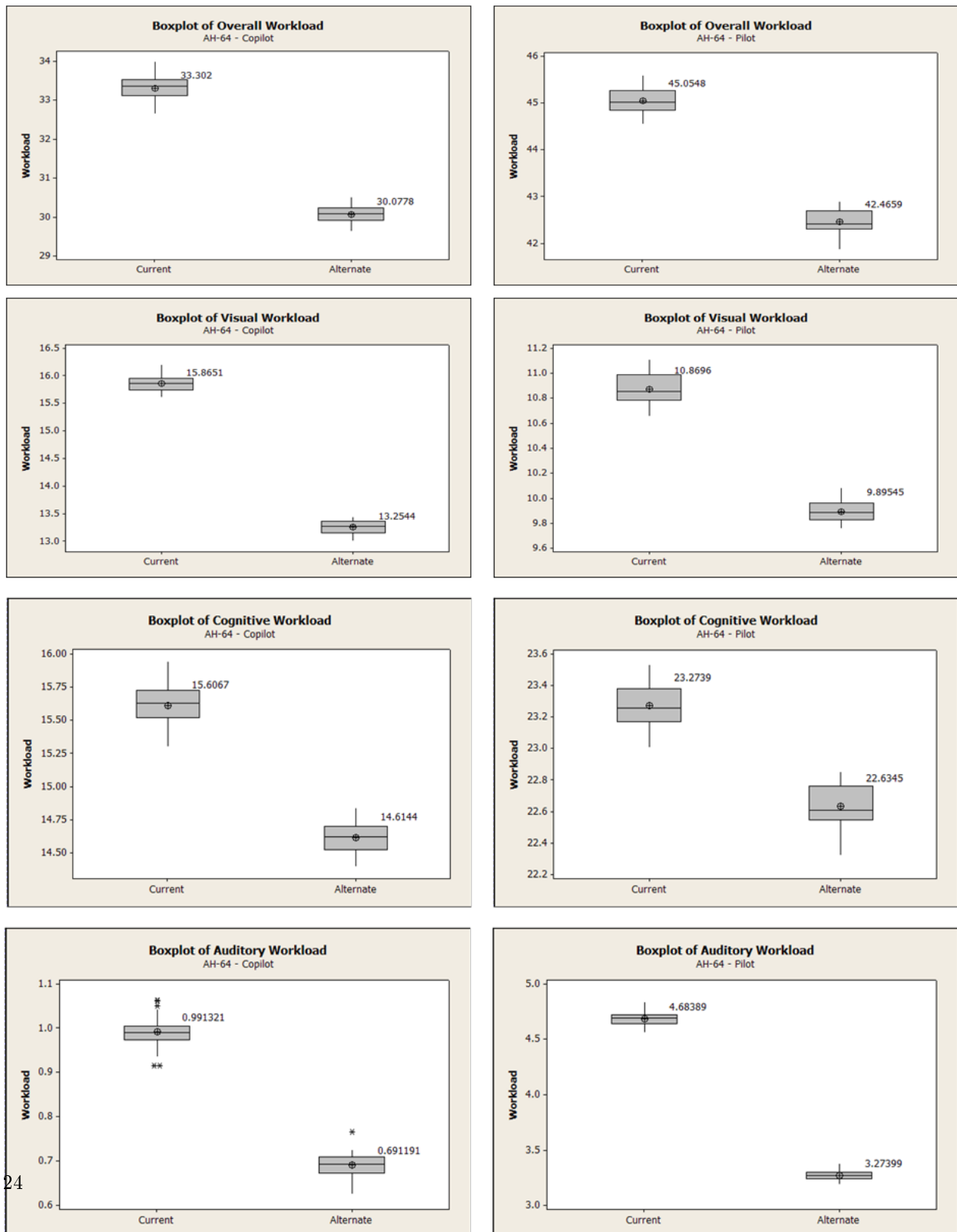


Figure 13: AH-64D Resource Boxplots

non-standard event, and develop alternative ways to present them that information using underutilized resources, like the tactile sense, thereby re-distributing the workload to other channels, so that pilots don't miss the crucial piece of information at the time when they need it.

This study has attempted to give a scenario driven hierarchy of information requirements for pilots and has demonstrated, using a non-human-in-the-loop computer simulation, that haptic technologies combined with 3D audio significantly reduce both individual resource and overall workload experienced by pilots and copilots. The Tactile Situation Awareness System, or TSAS, and the soft actuator technologies discussed in section 5 are the most viable haptic technologies for use in future cockpits based on tactor quality, current cockpit design vs. re-design issues, ease of use, cost effectiveness, and can have the greatest impact on reducing workload. An optimal HUD symbology layout, based on either Layout Appropriateness or pilot habit patterns as described in section 6, has the potential, although further study is needed to actually prove this, to increase pilot situational awareness and reduce workload. A potential way of evaluating different HUD symbologies is to use the same methodology as this study did, by using IMPRINT to compare alternatives. The only issue here would be the level of fidelity in the simulation itself. It remains questionable whether heads up displays can be created in the current version of the simulation given its underlying code structure, but a new version of IMPRINT will be out later this year and this approach may be viable. Further study is also needed in regards to symbology contrast and color schemes. While the BOLD Symbology SBIR touched on this, indicating that black symbology against a light background, and white symbology against dark, will probably work best, further research needs to be done on this topic in order to find a definitive answer, especially in regards to the "regular" HUD, and not when applied under brown-out or DVE conditions.

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Nomenclature

AMC	Air Mission Commander
ANOVA	Analysis of Variance
ARL	Army Research Lab
BOLD	Brown-Out Landing Display
CMWS	Common Missile Warning System
DVE	Degraded Visual Environments
FRAGO	Fragmentary Order
GWOT	Global War on Terror
HRED	Human Research and Engineering Directorate
HUD	Heads Up Display
ICS	Internal Communication System
IMPRINT	Improved Performance Research Integration Tool
KIAS	Knots in Airspeed
LA	Layout Appropriateness
LZ	Landing Zone
NAMRL	Naval Aerospace Medical Research Lab
PEO	Program Executive Office
PFD	Primary Flight Display
PZ	Pick-up Zone
RPGs	Rocket Propelled Grenades
SA	Situational Awareness
SBIR	Small Business Innovation Research
TSAS	Tactile Situation Awareness System
USAARL	United States Army Aeromedical Research Lab
USAFRL	United States Air Force Research Lab
VFR	Visual Flight Rules

Appendix A - Complete Functional Analysis of UH-60 Scenario

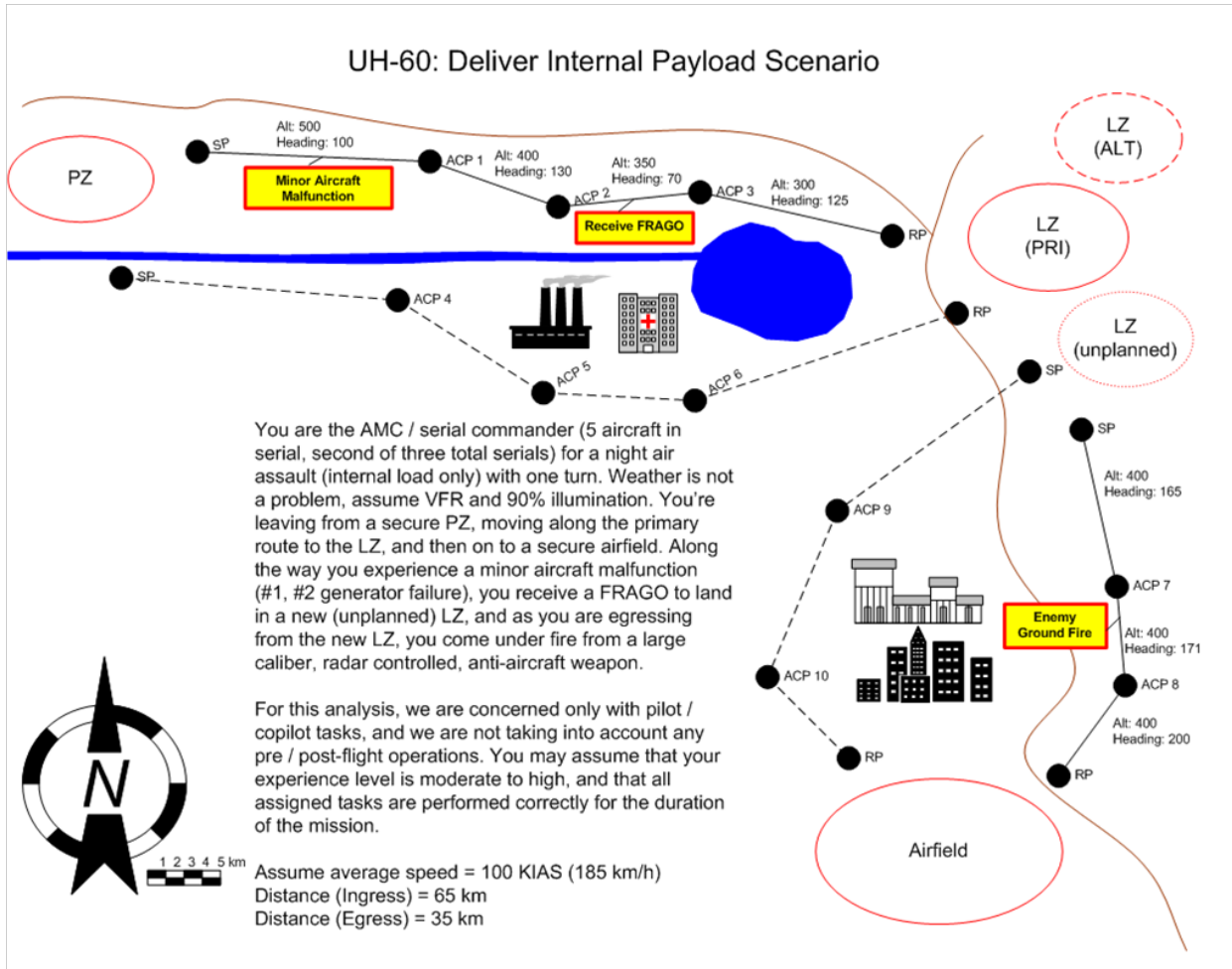


Figure 14: UH-60 Scenario Description

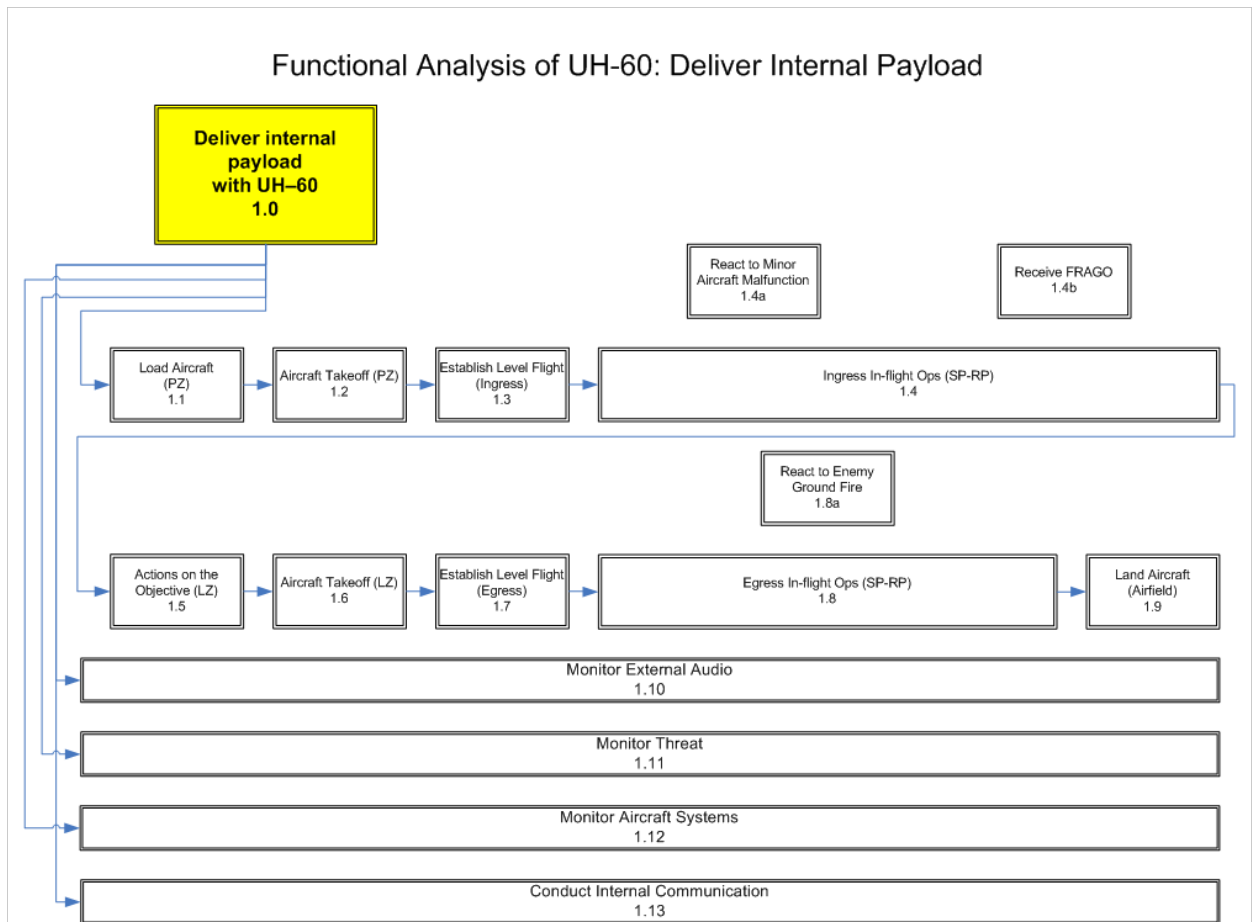


Figure 15: Top Level Functional Analysis

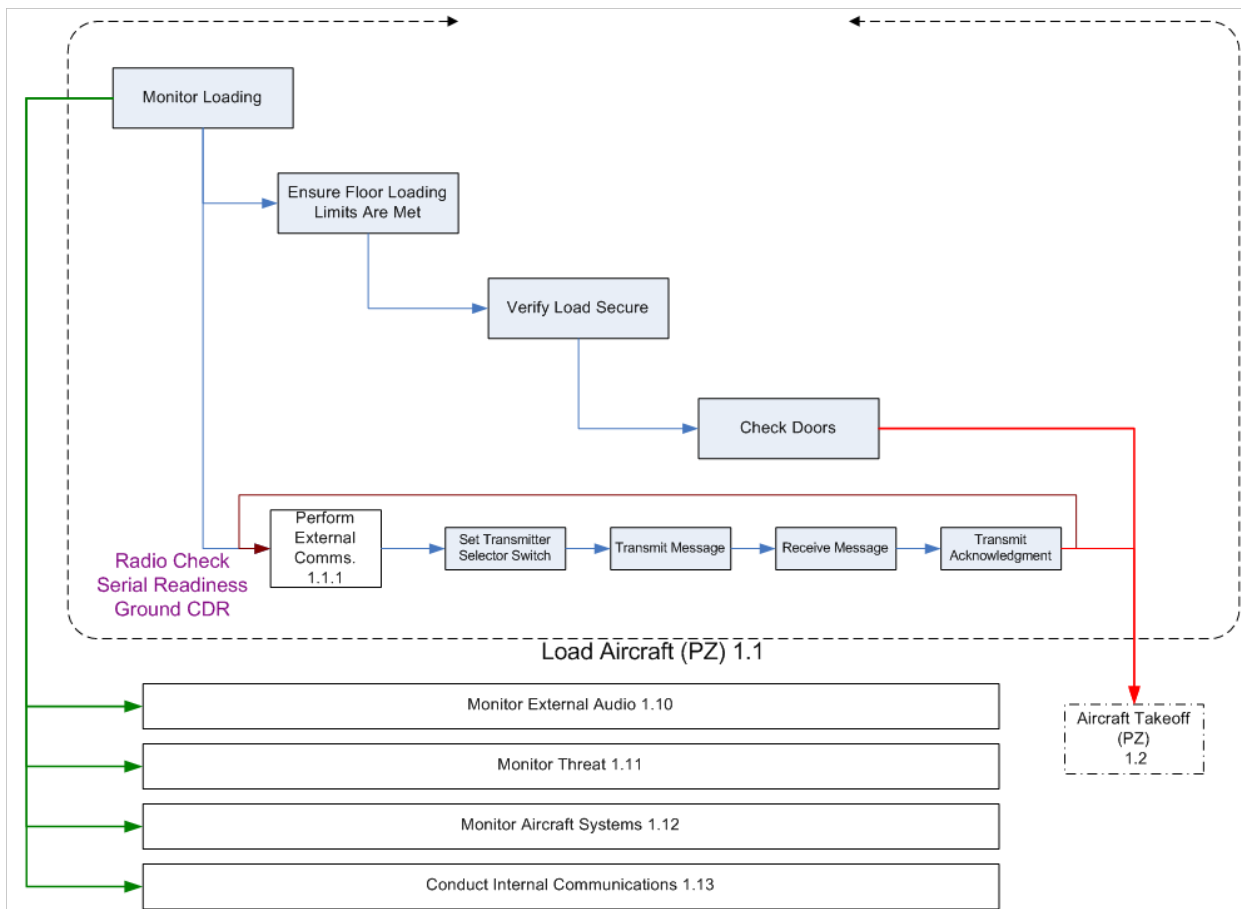


Figure 16: Load Aircraft

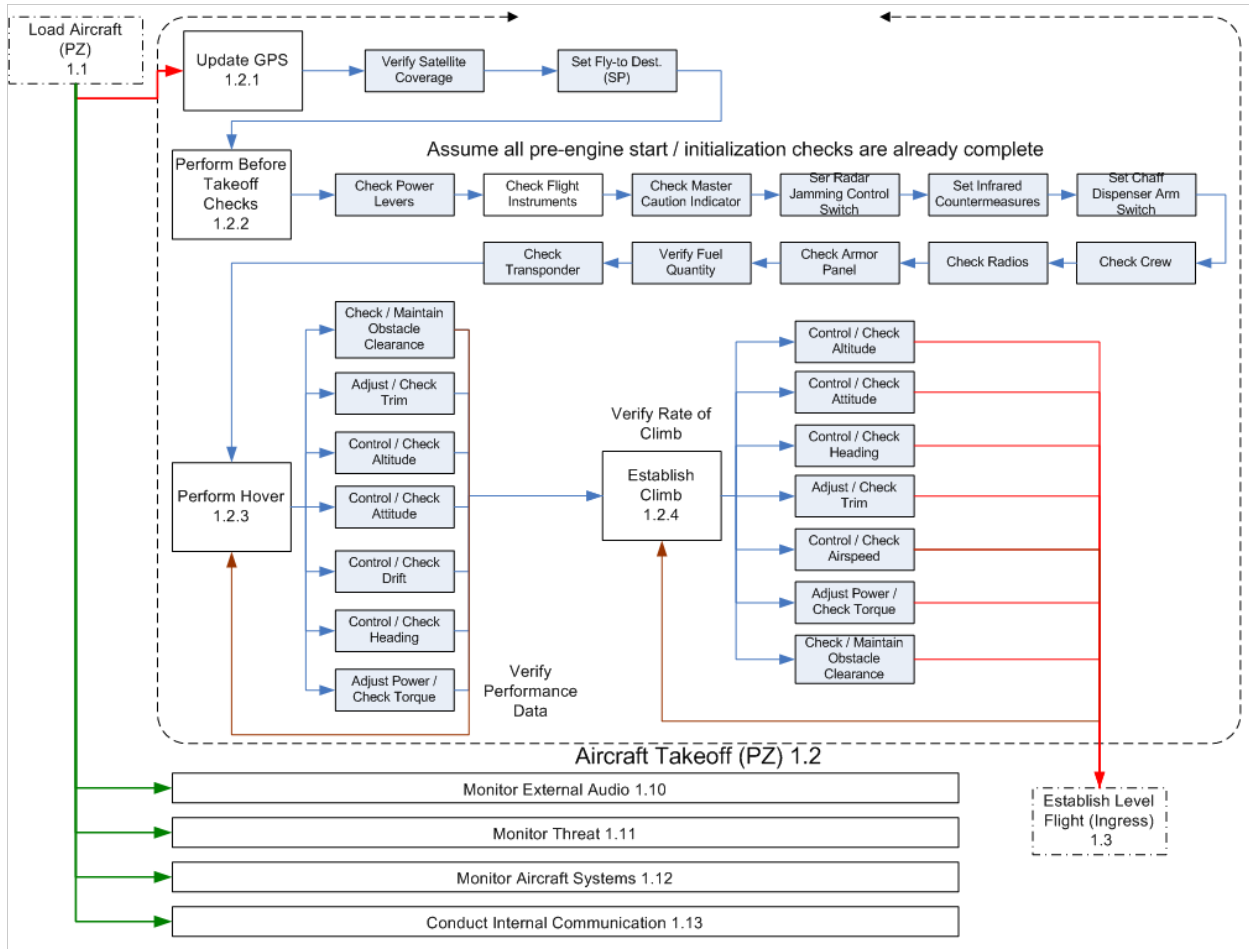


Figure 17: Aircraft Takeoff

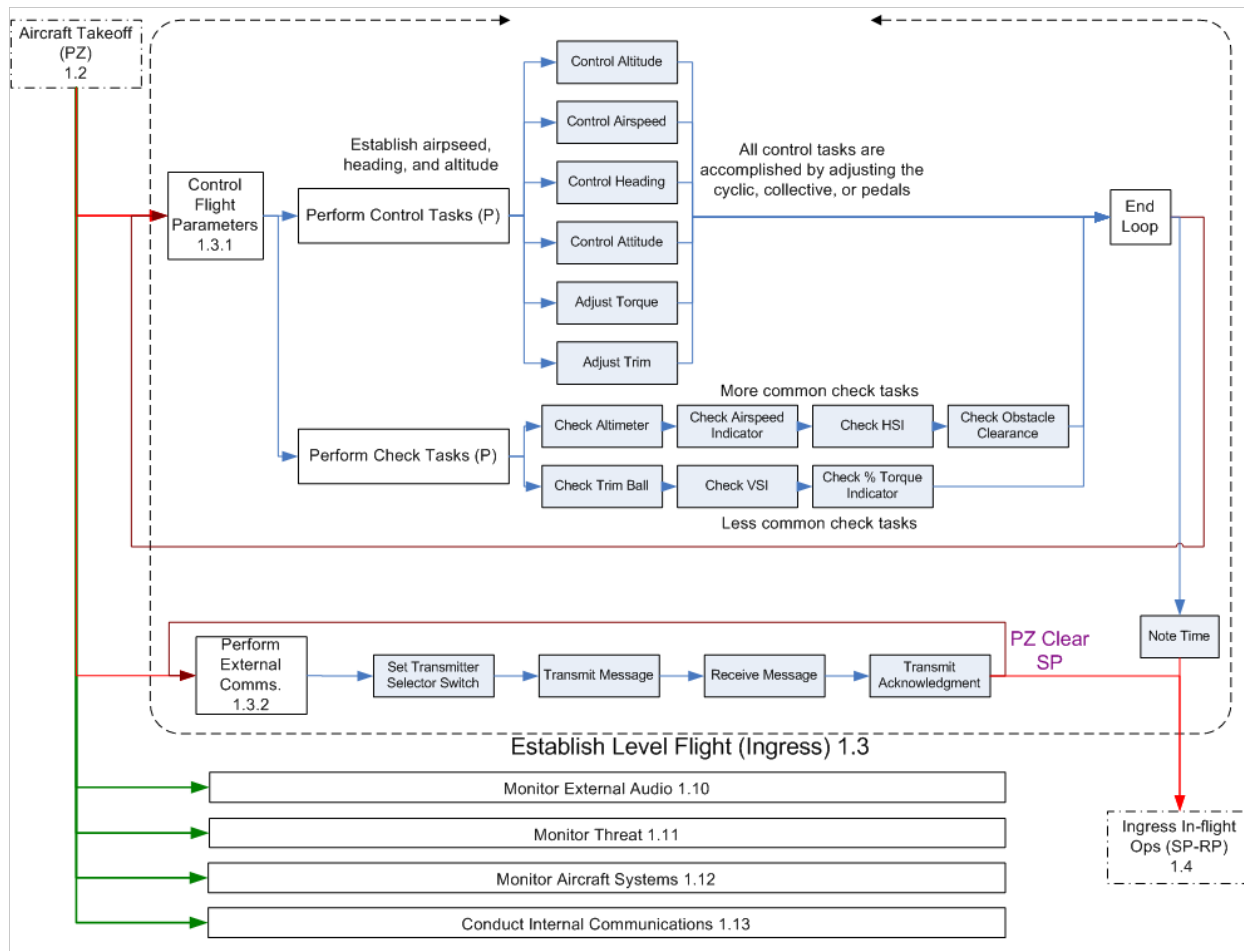


Figure 18: Level Flight (Ingress)

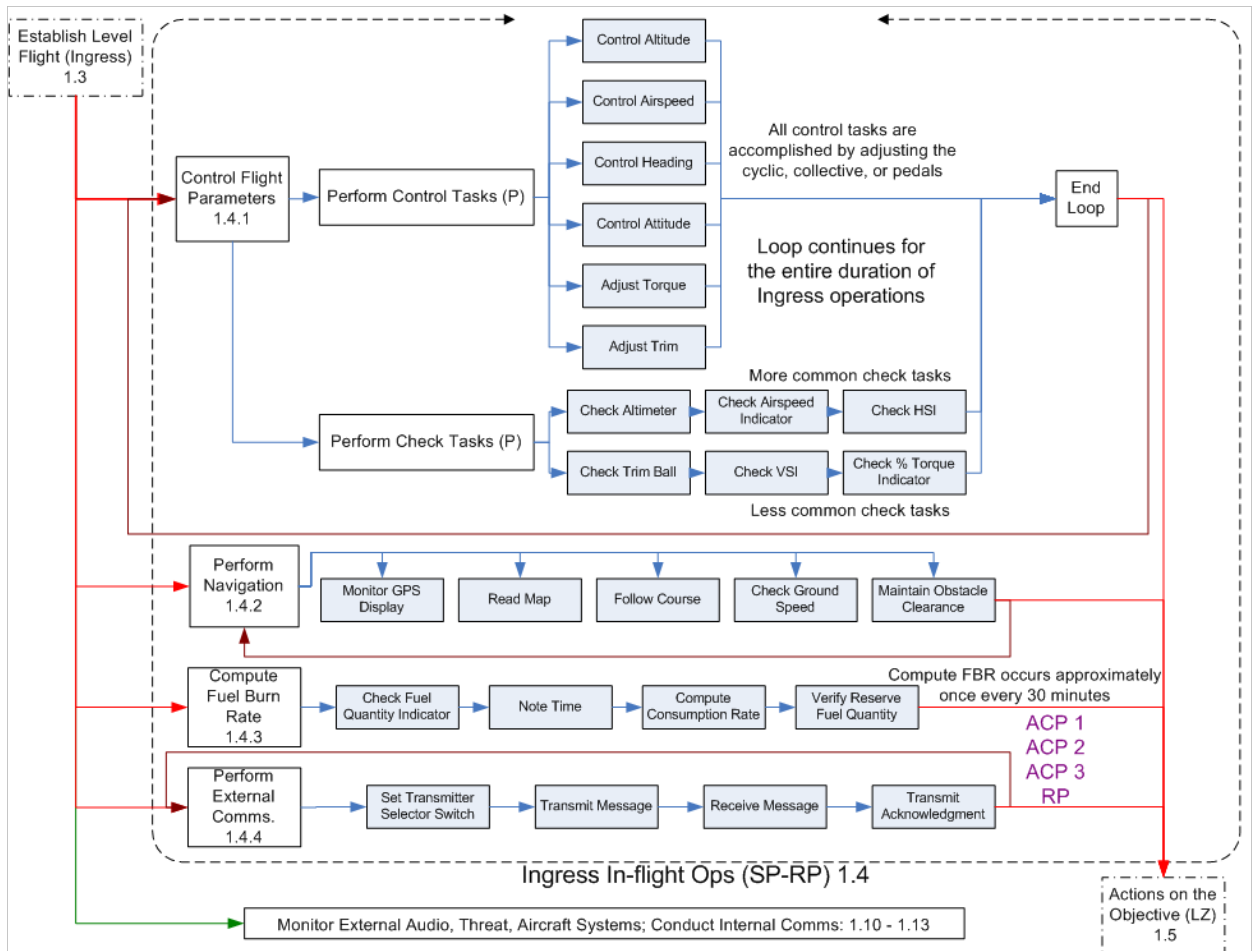


Figure 19: Ingress

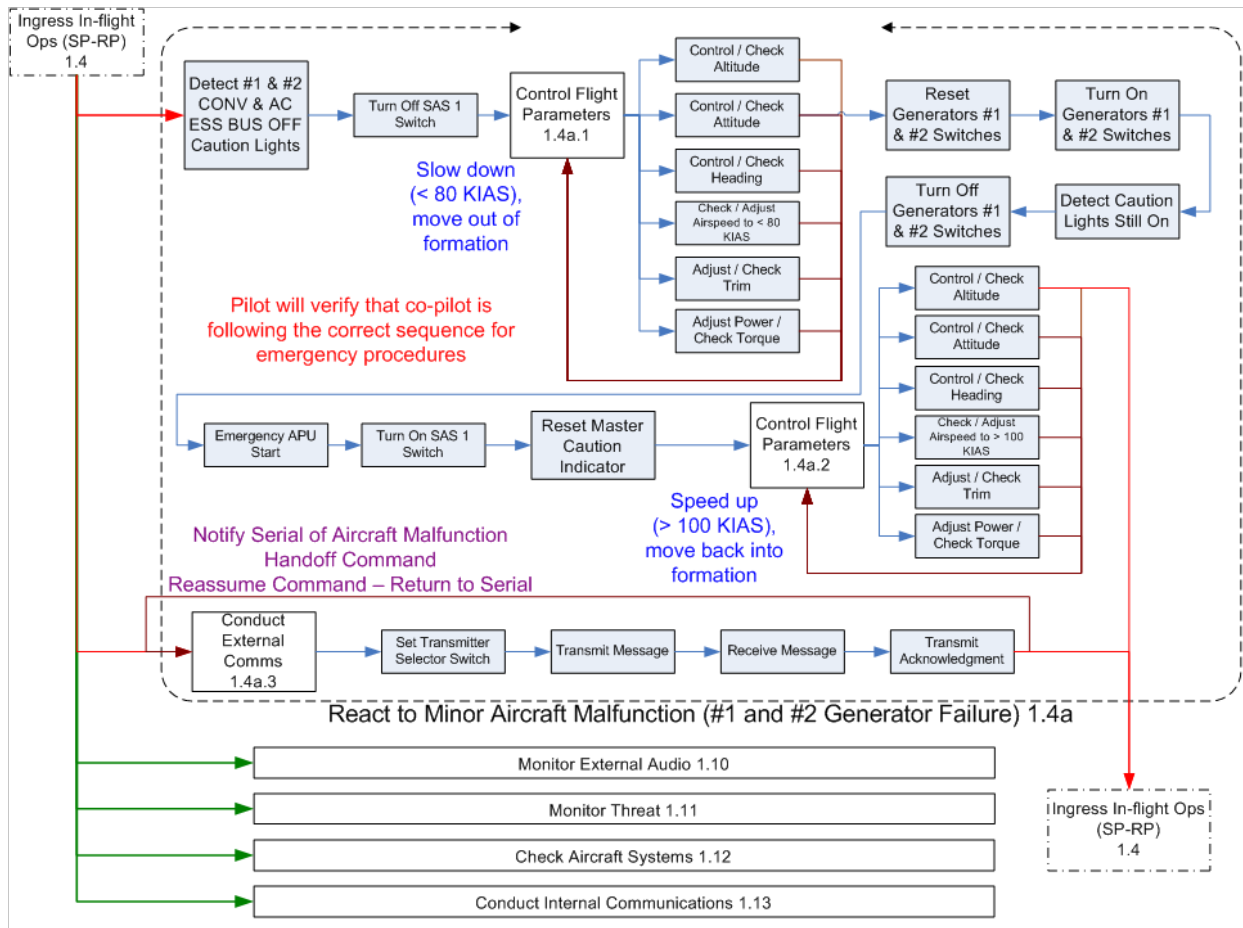


Figure 20: Malfunction

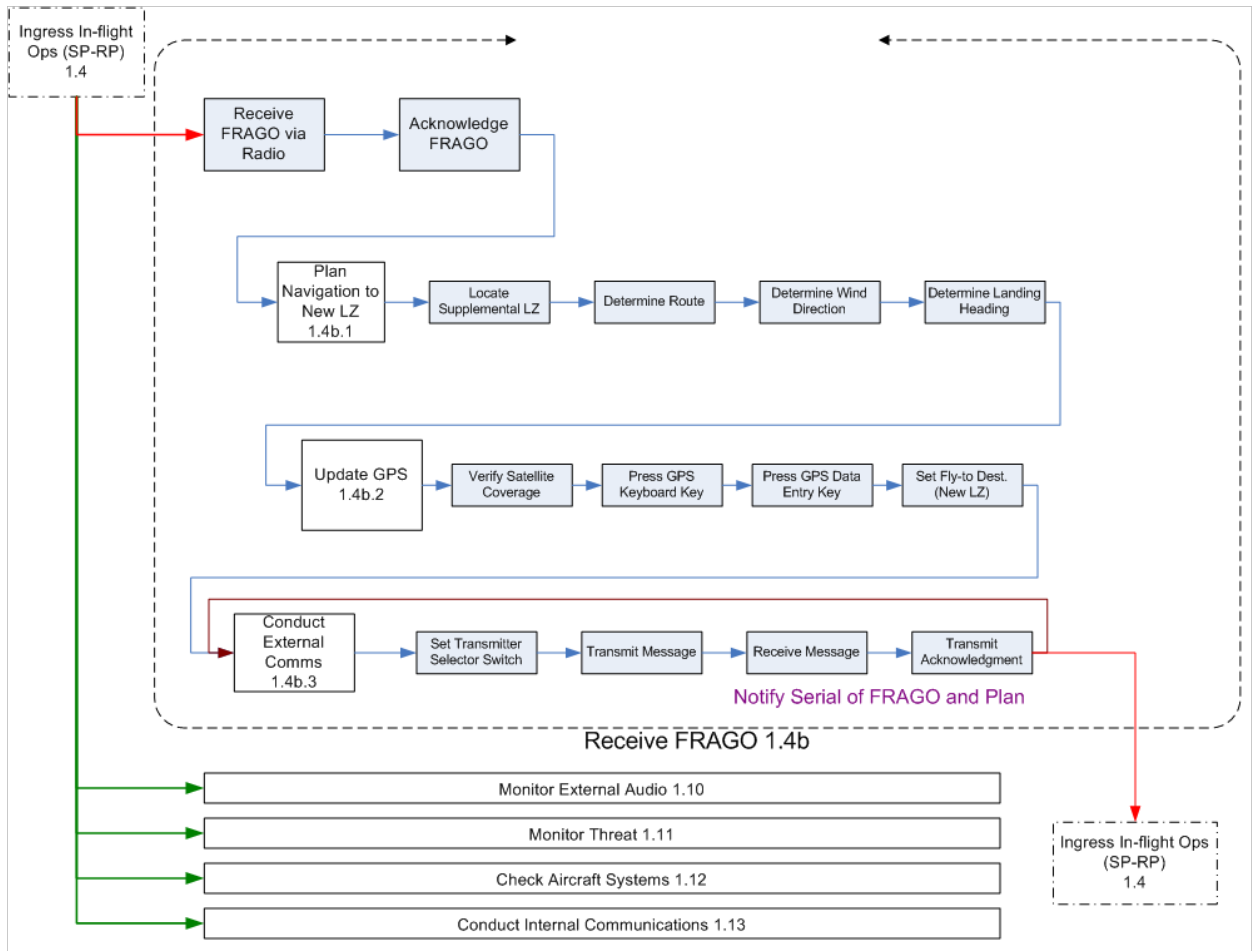


Figure 21: FRAGO

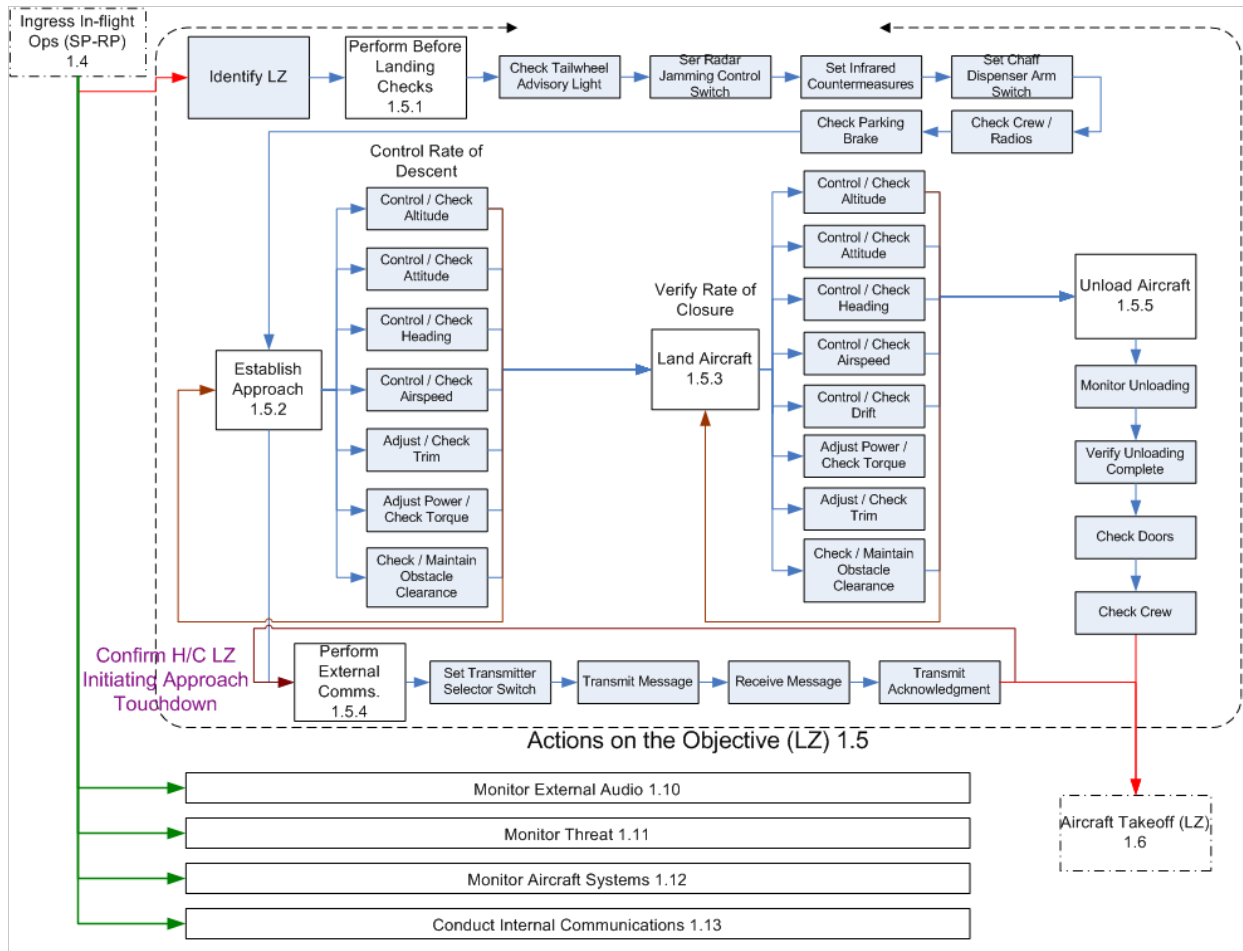


Figure 22: Objective

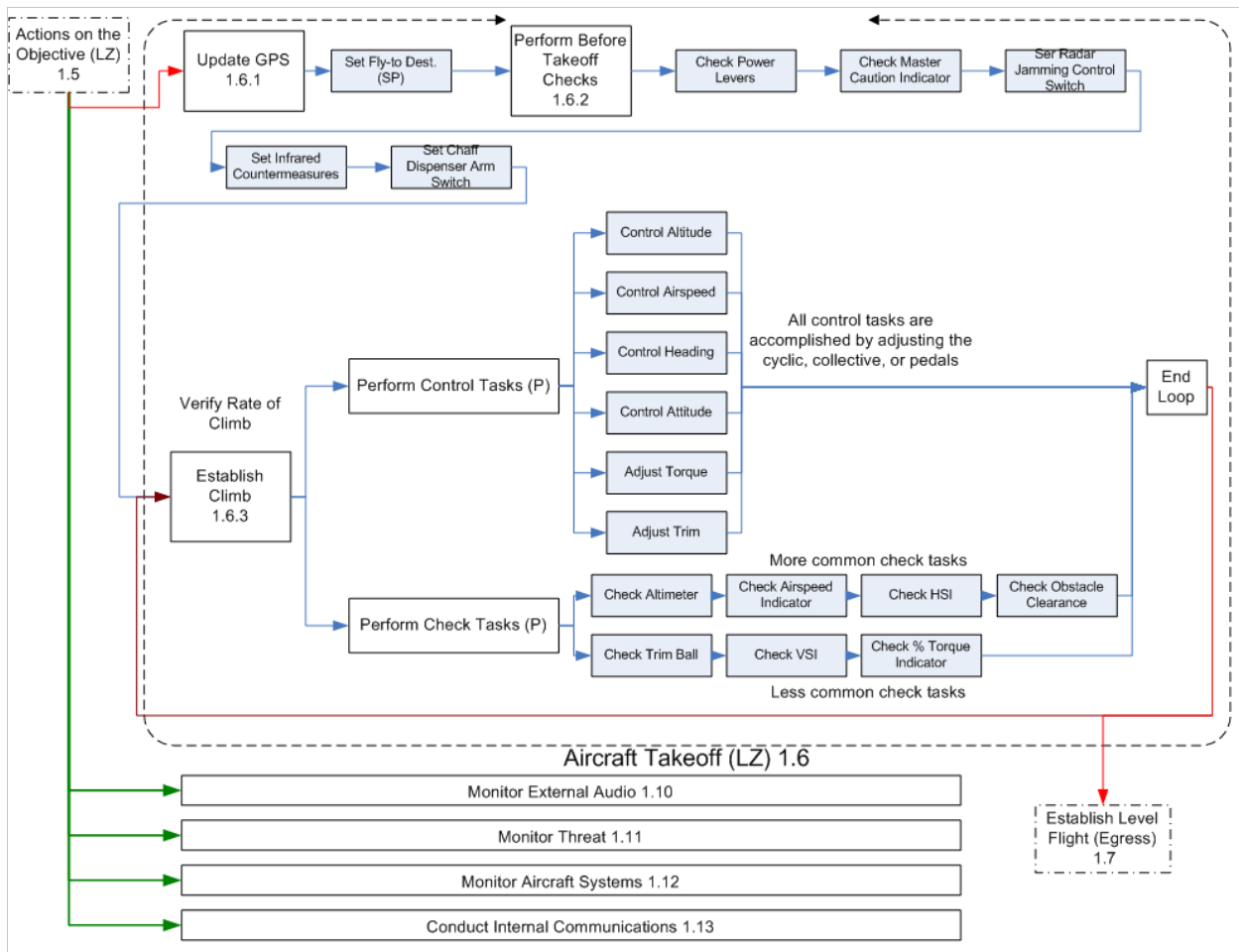


Figure 23: Takeoff

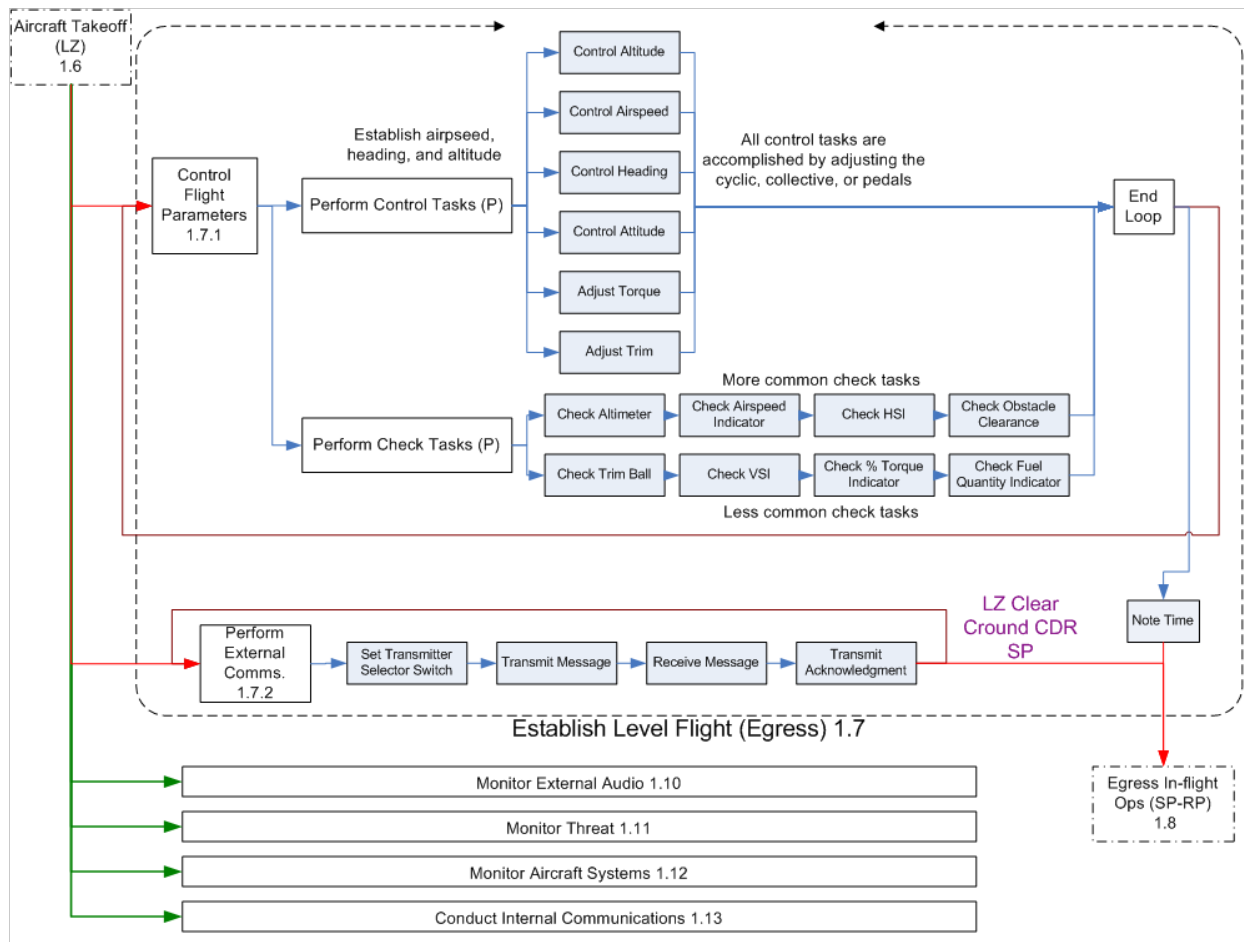


Figure 24: Level Flight (Egress)

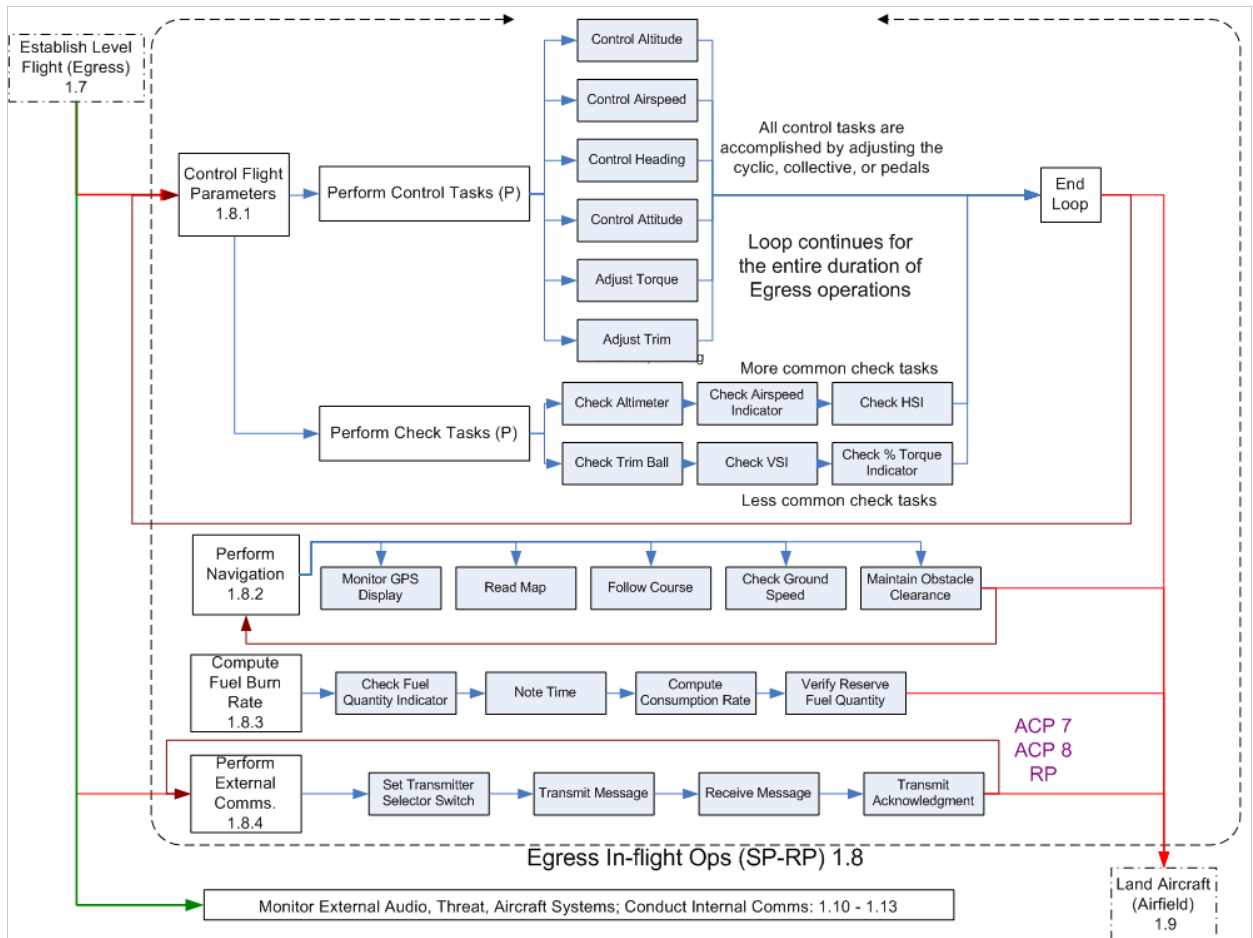


Figure 25: Egress

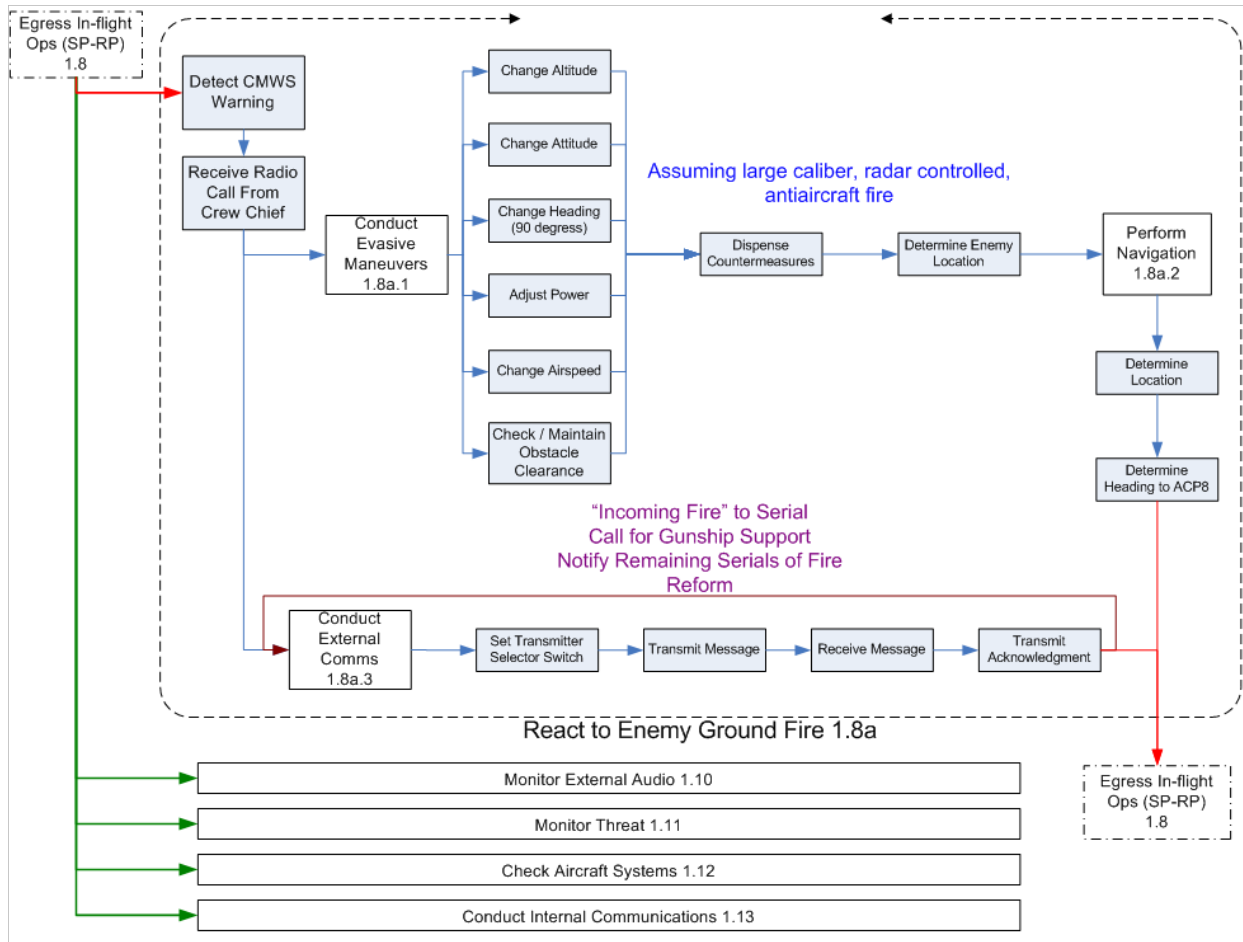


Figure 26: Ground Fire

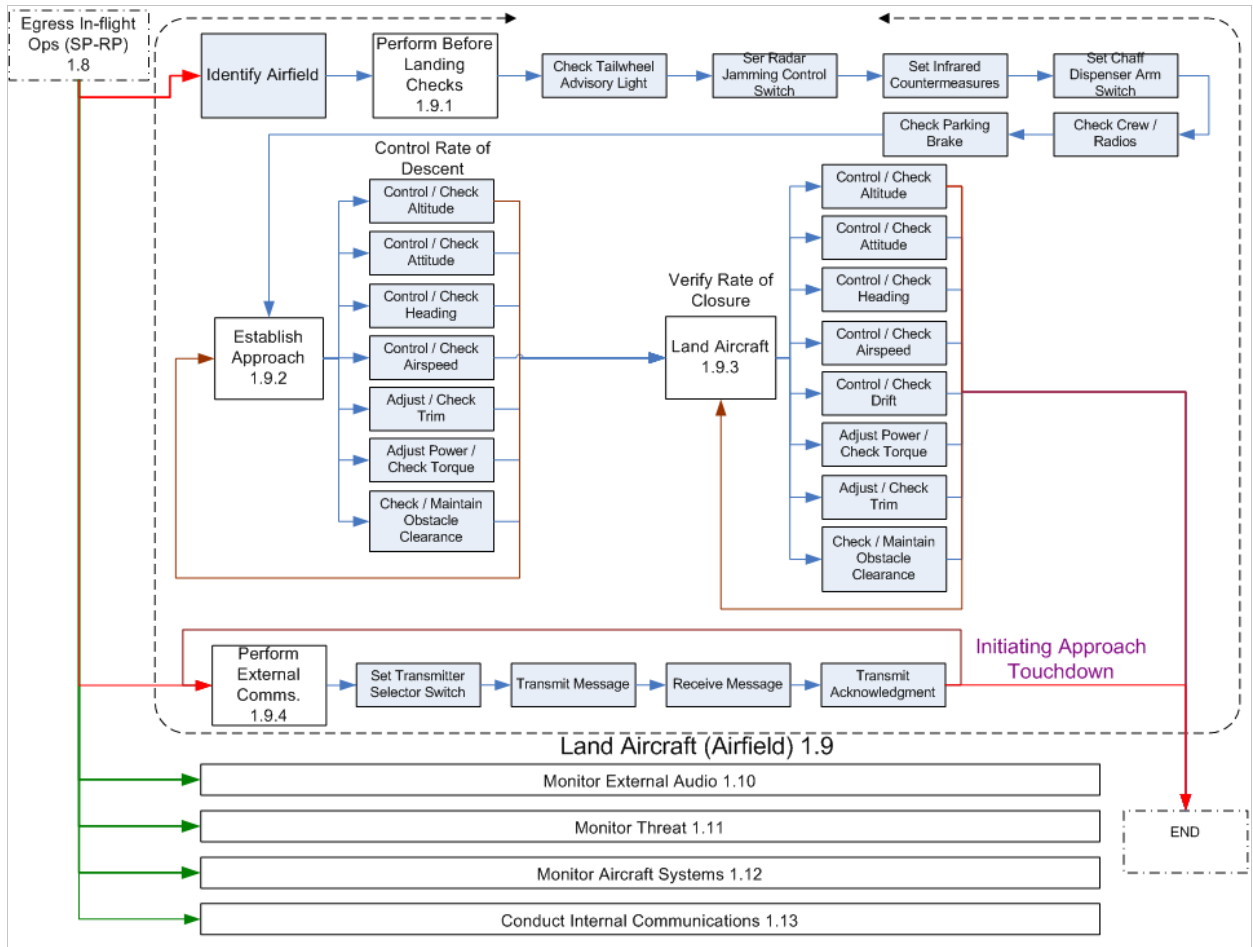


Figure 27: Land Aircraft

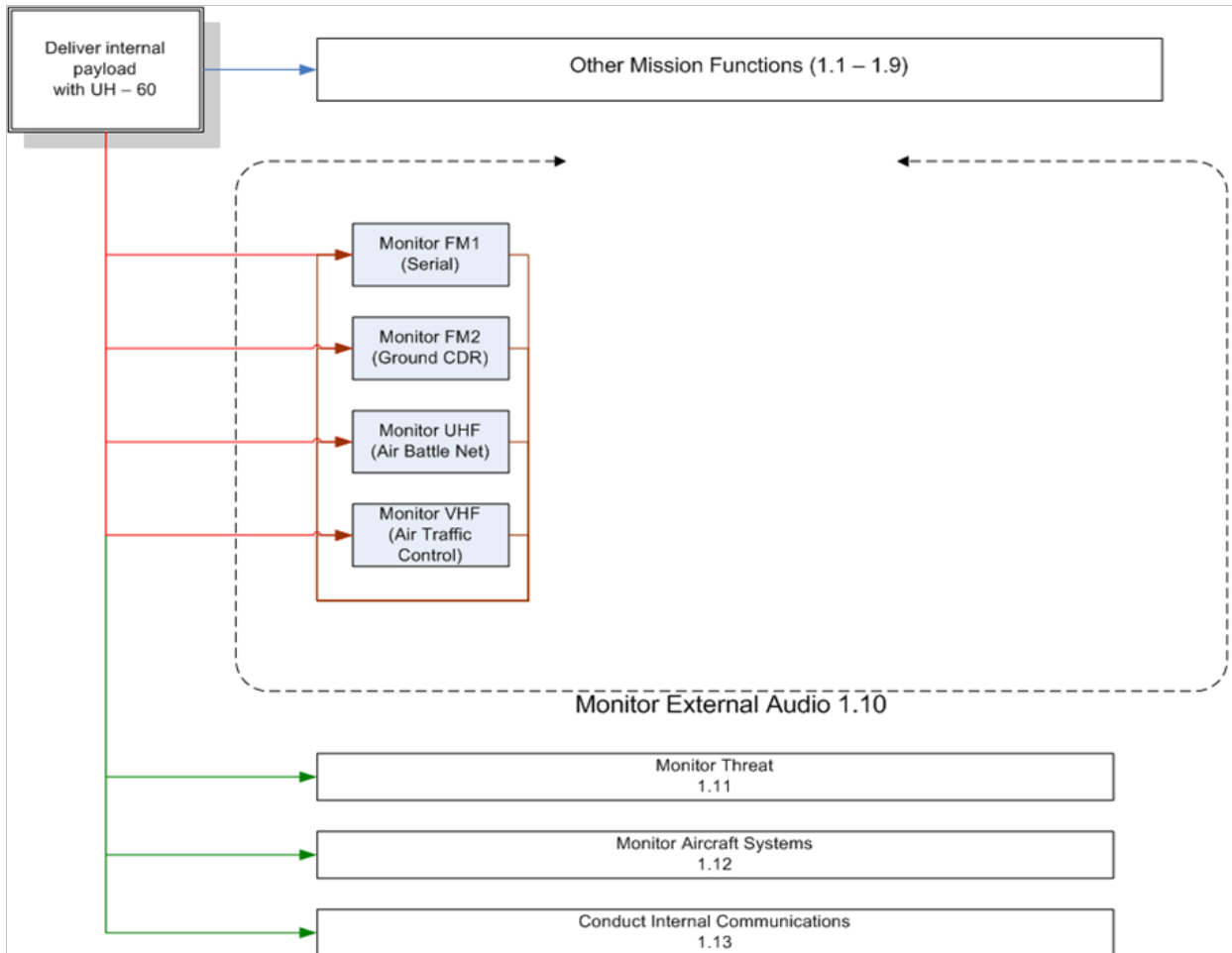


Figure 28: Internal Audio

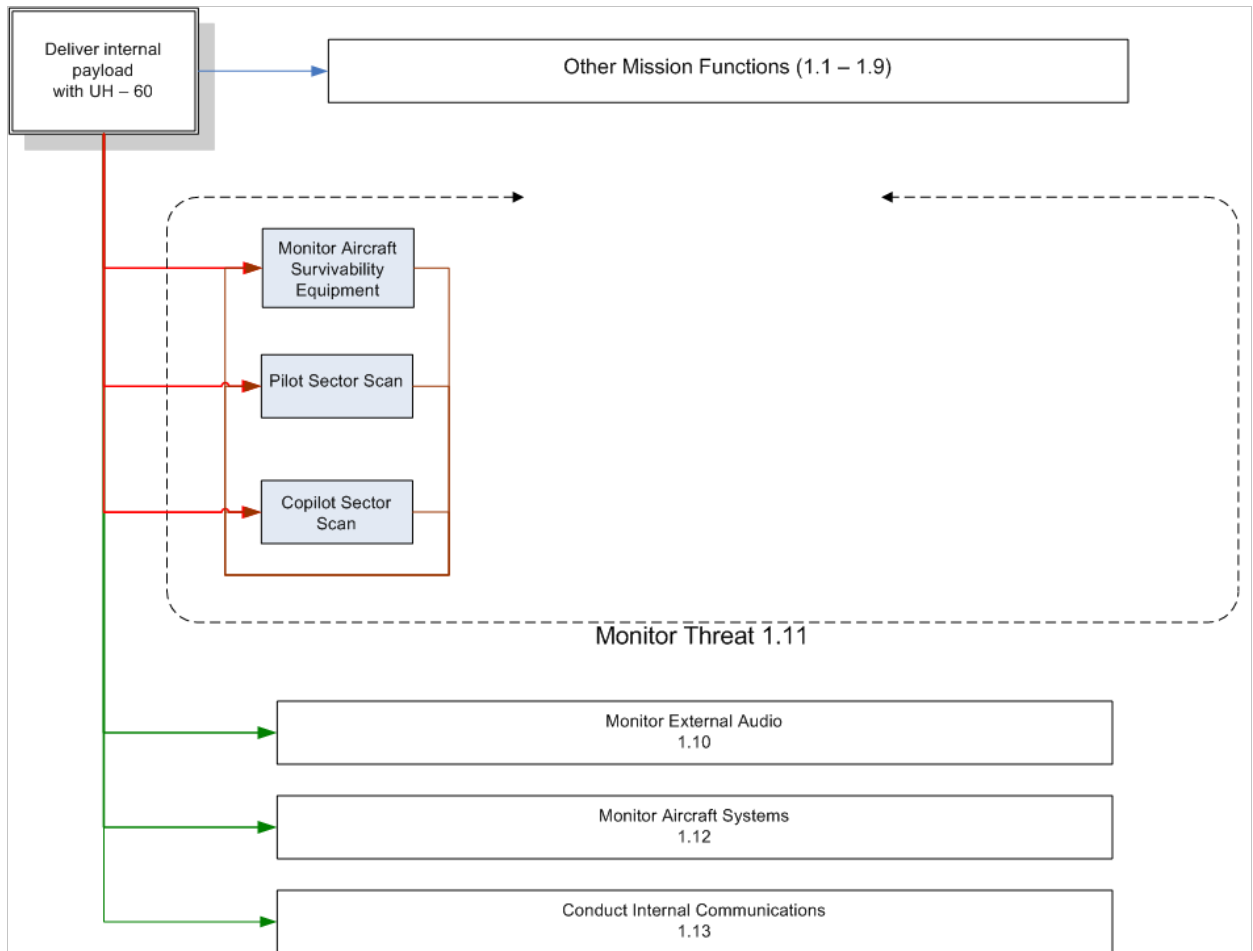


Figure 29: Threat

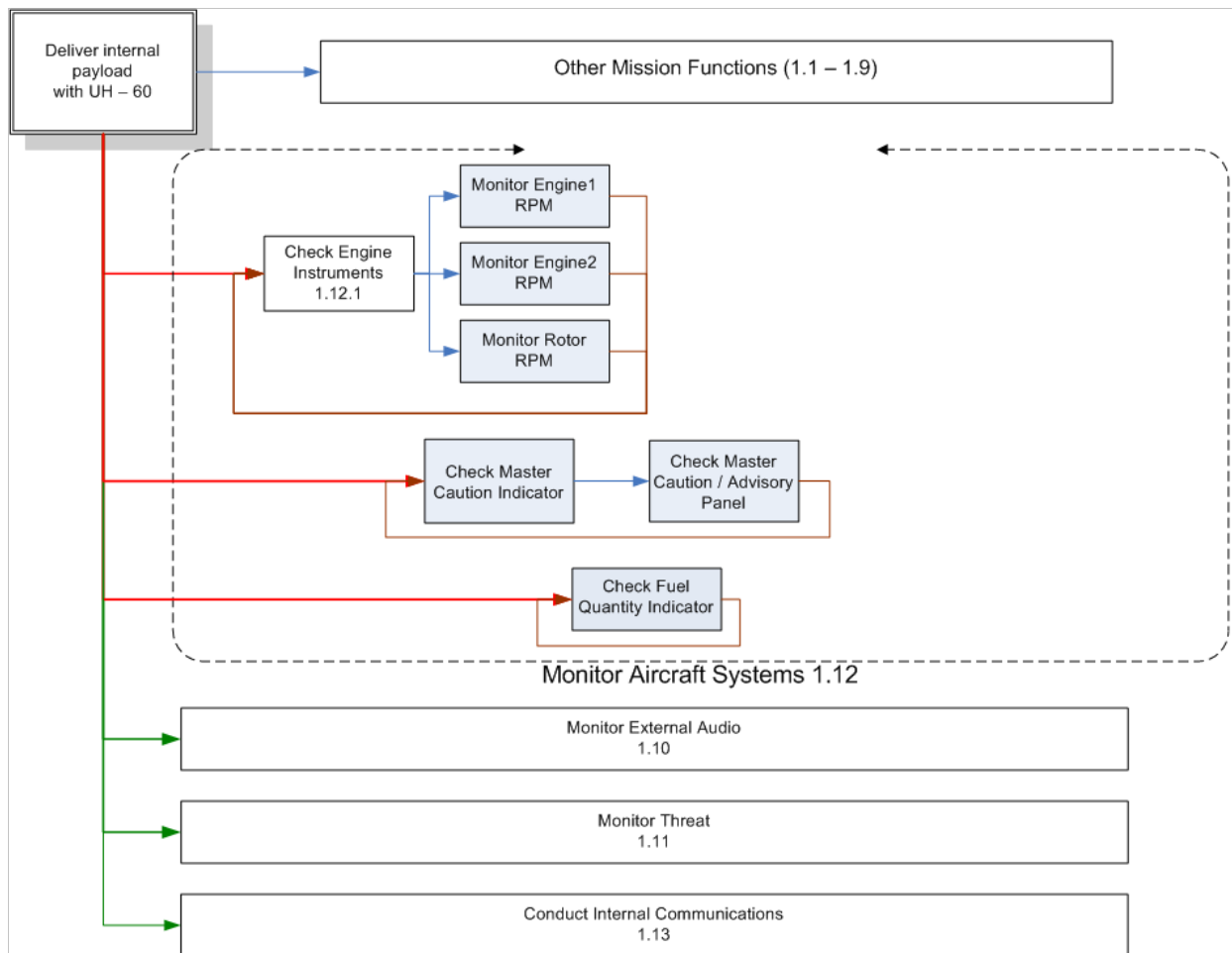


Figure 30: Aircraft Systems

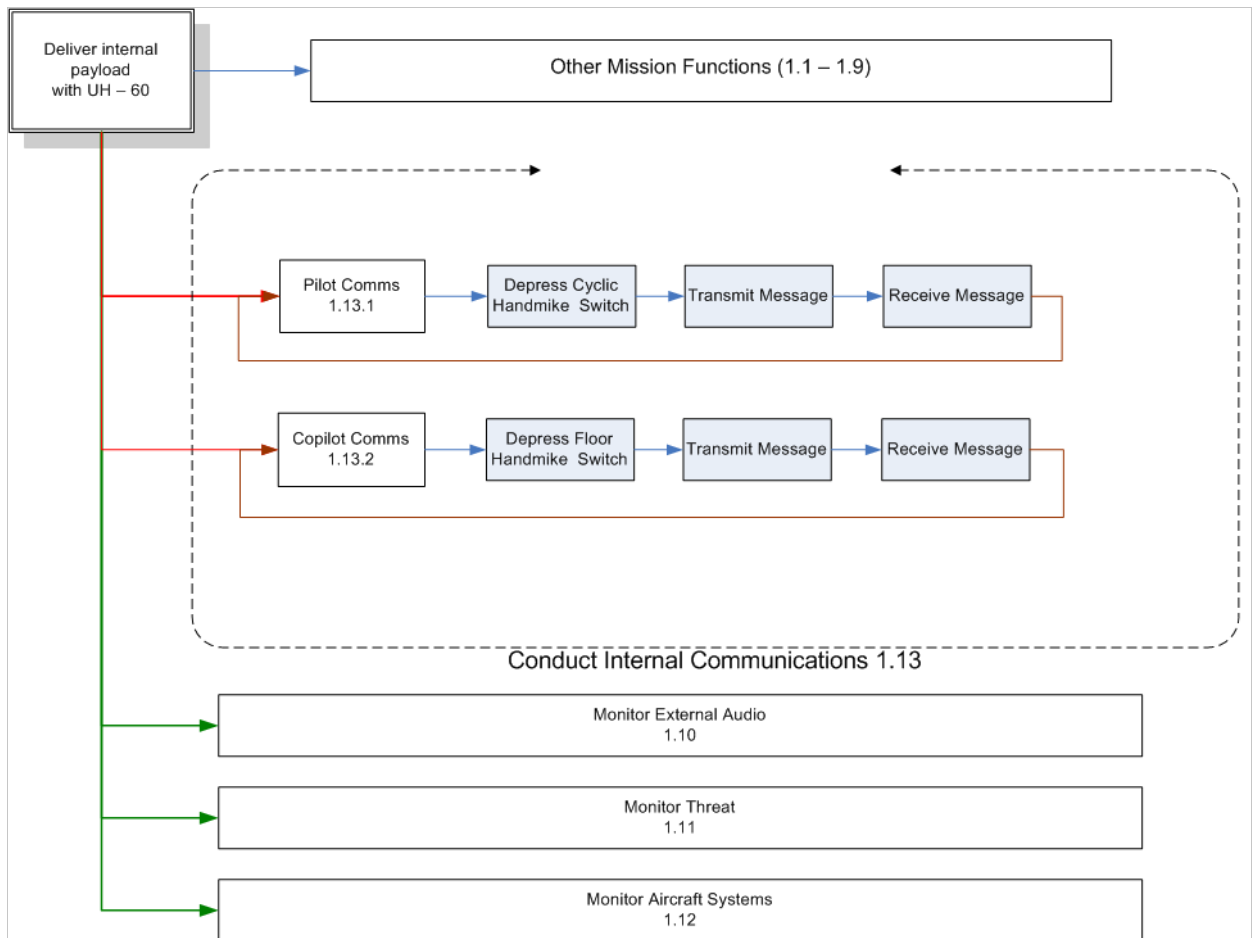


Figure 31: Internal Communication

Appendix B - Complete Functional Analysis of AH-64D Scenario

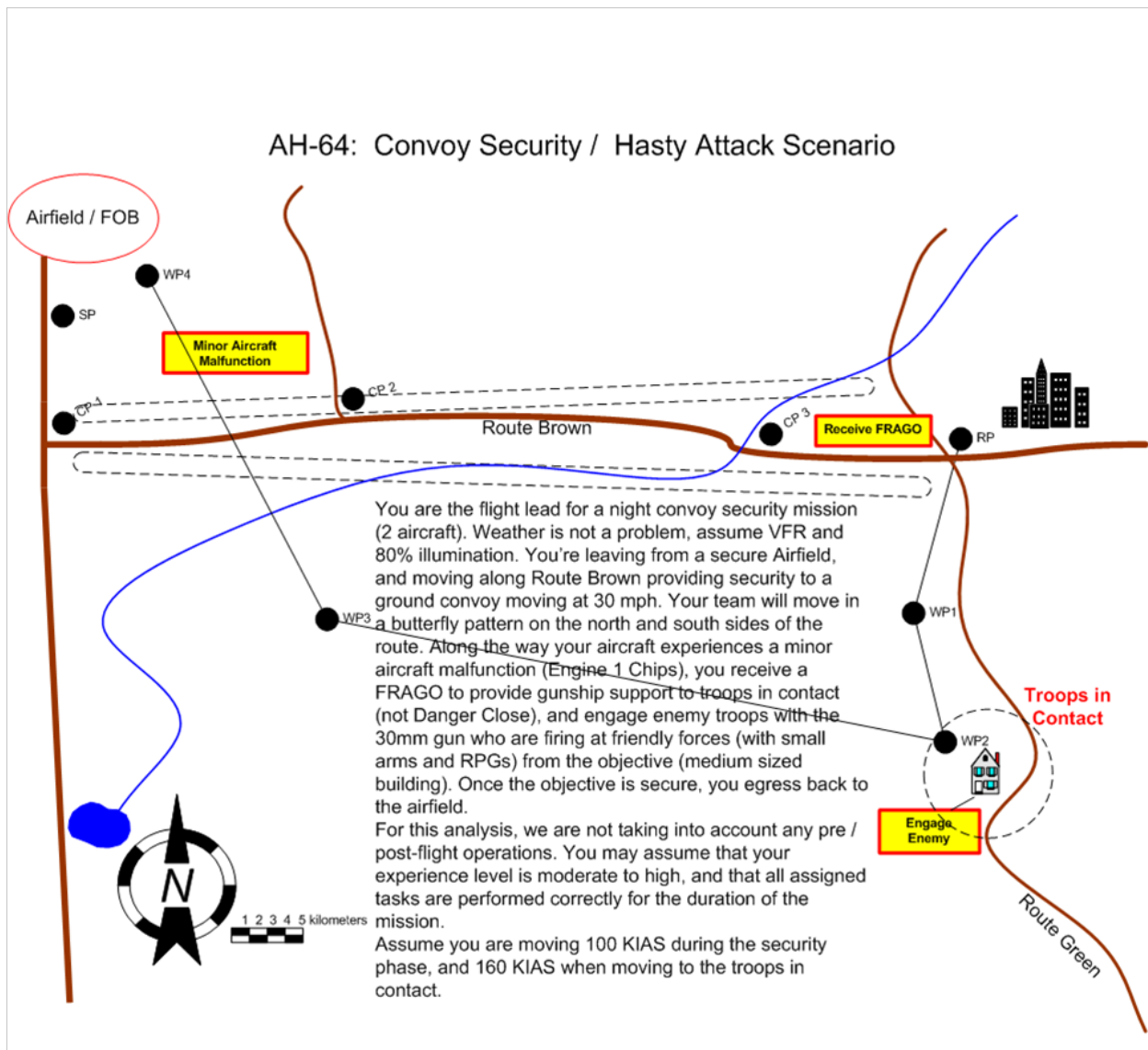


Figure 1: AH-64D Scenario

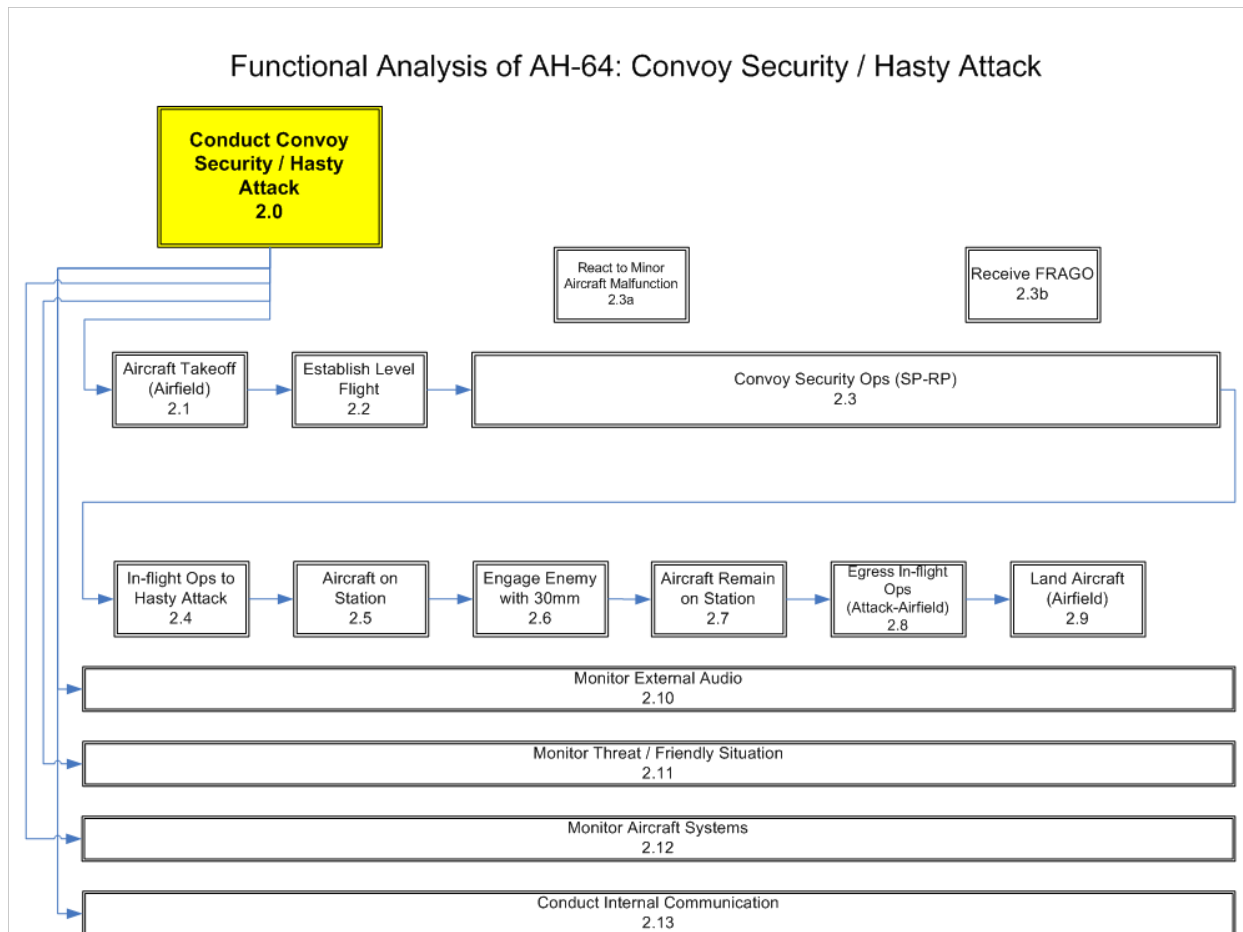


Figure 2: Top Level Functional Analysis

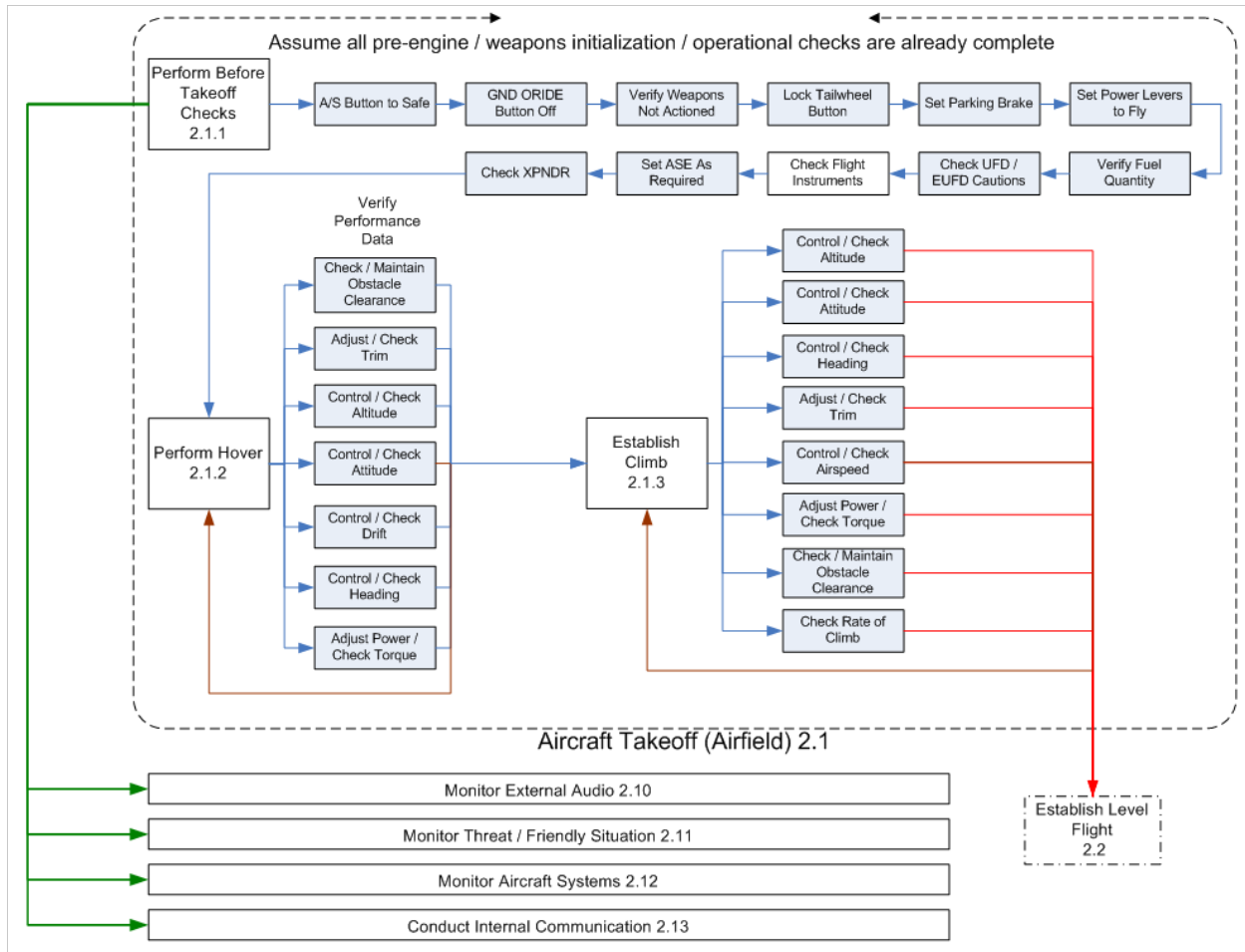


Figure 3: Takeoff

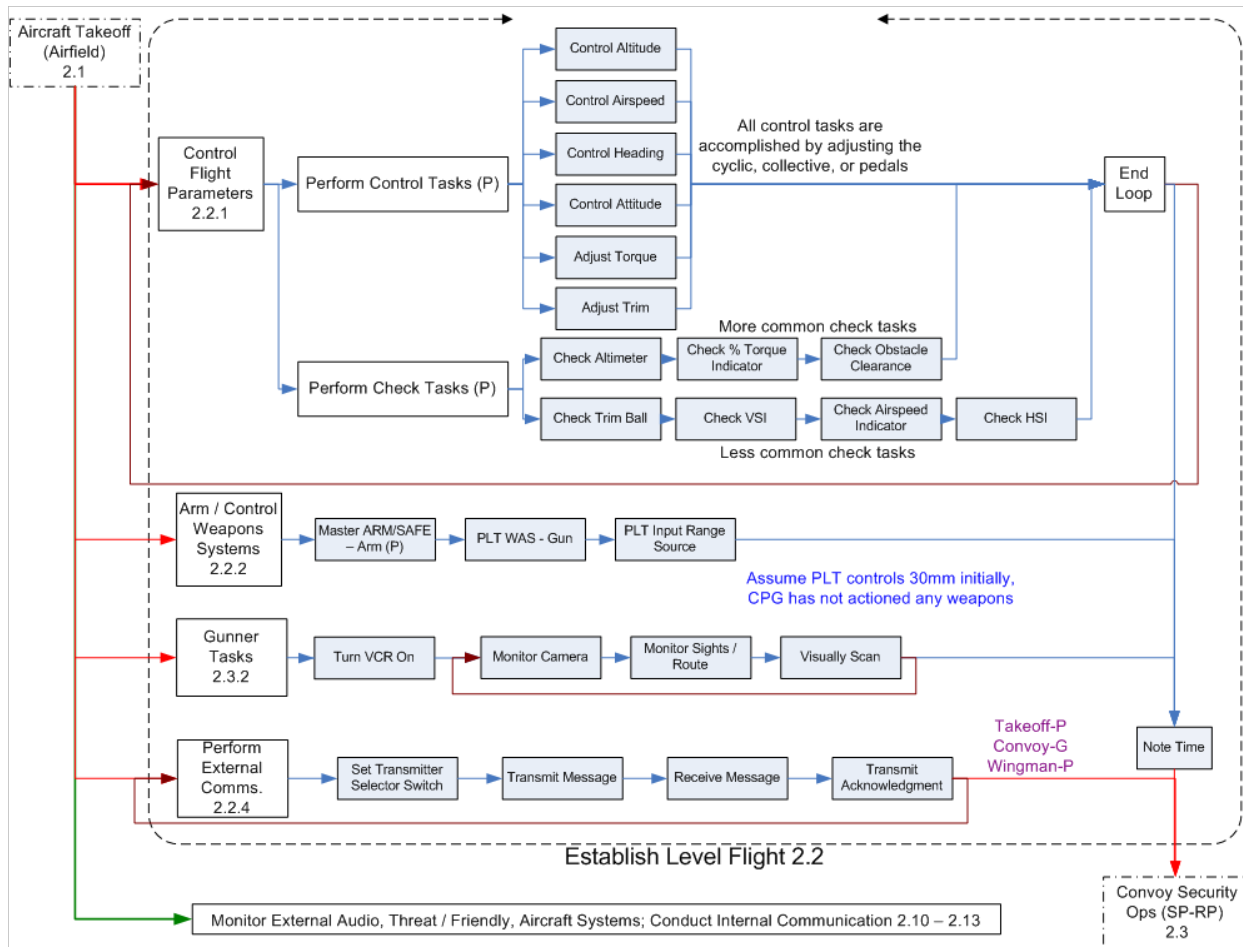


Figure 4: Level Flight

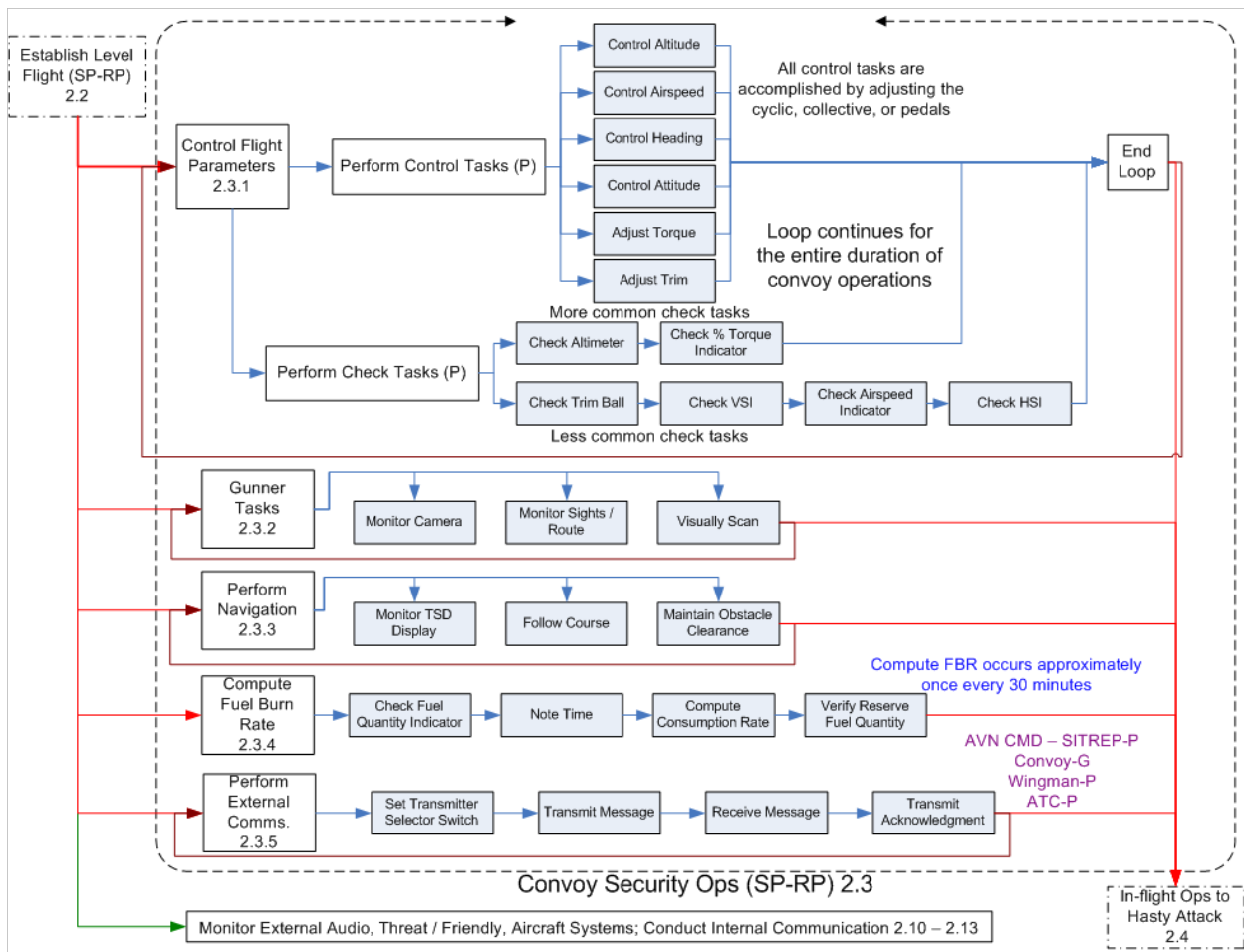


Figure 5: Security Ops

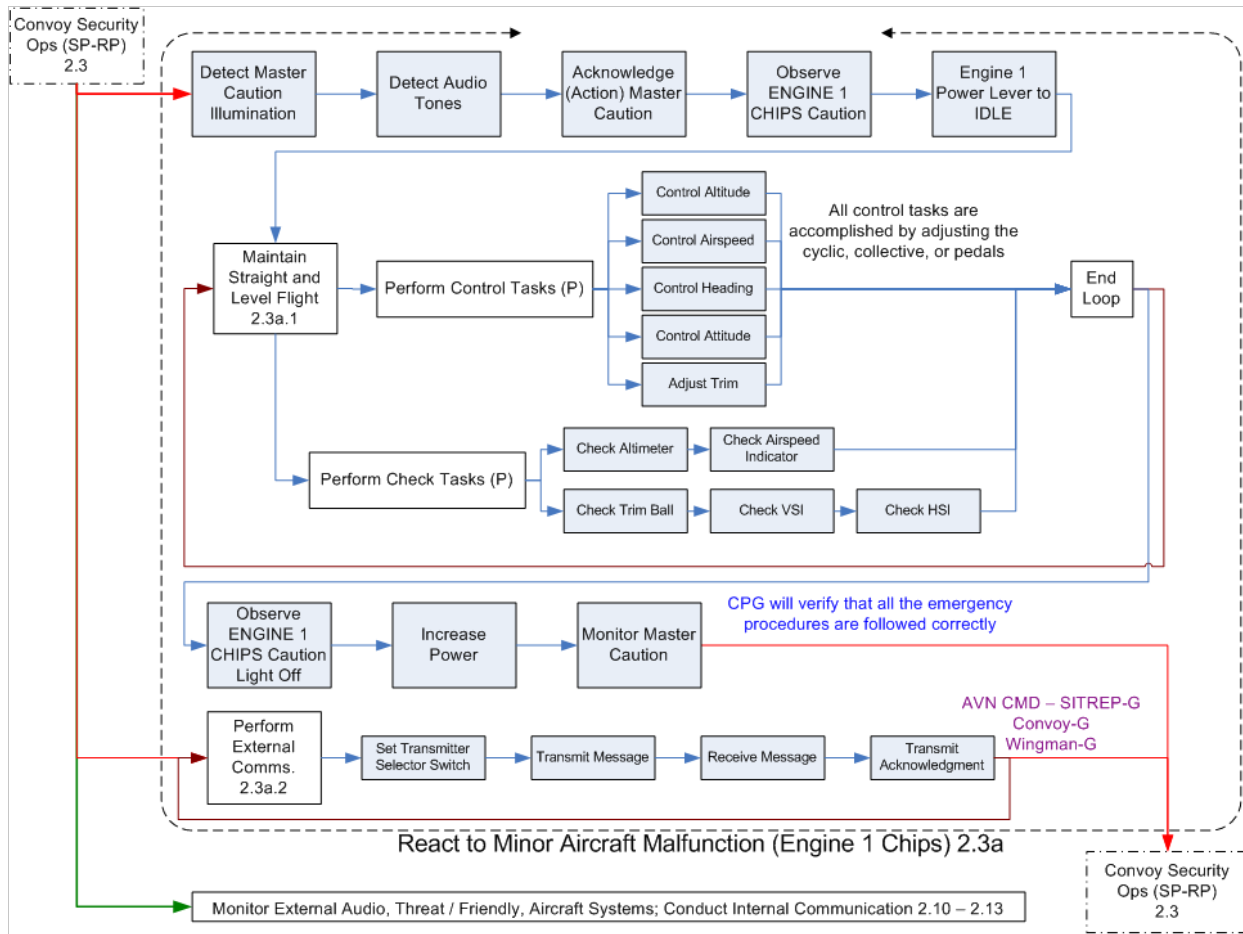


Figure 6: Malfunction

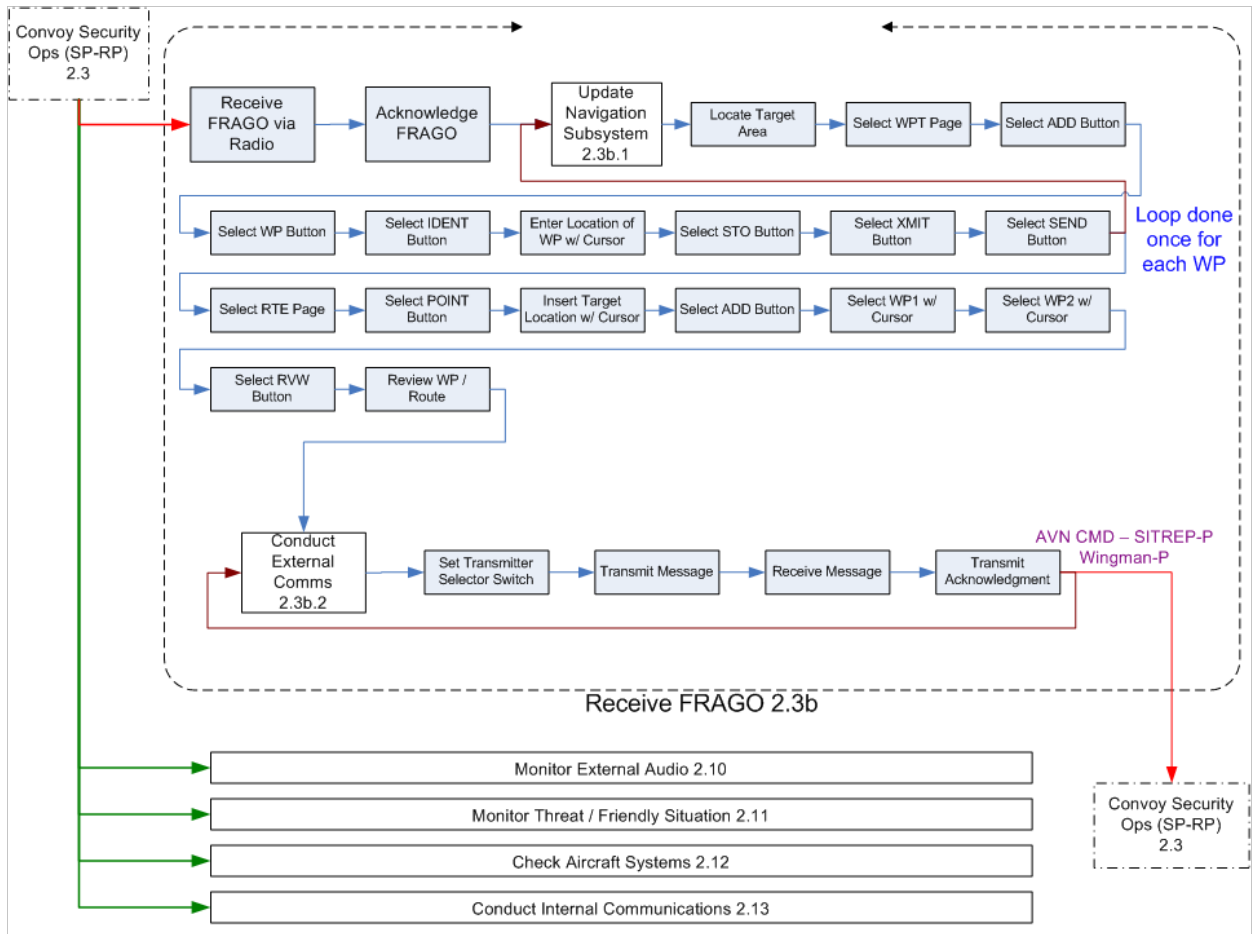


Figure 7: FRAGO

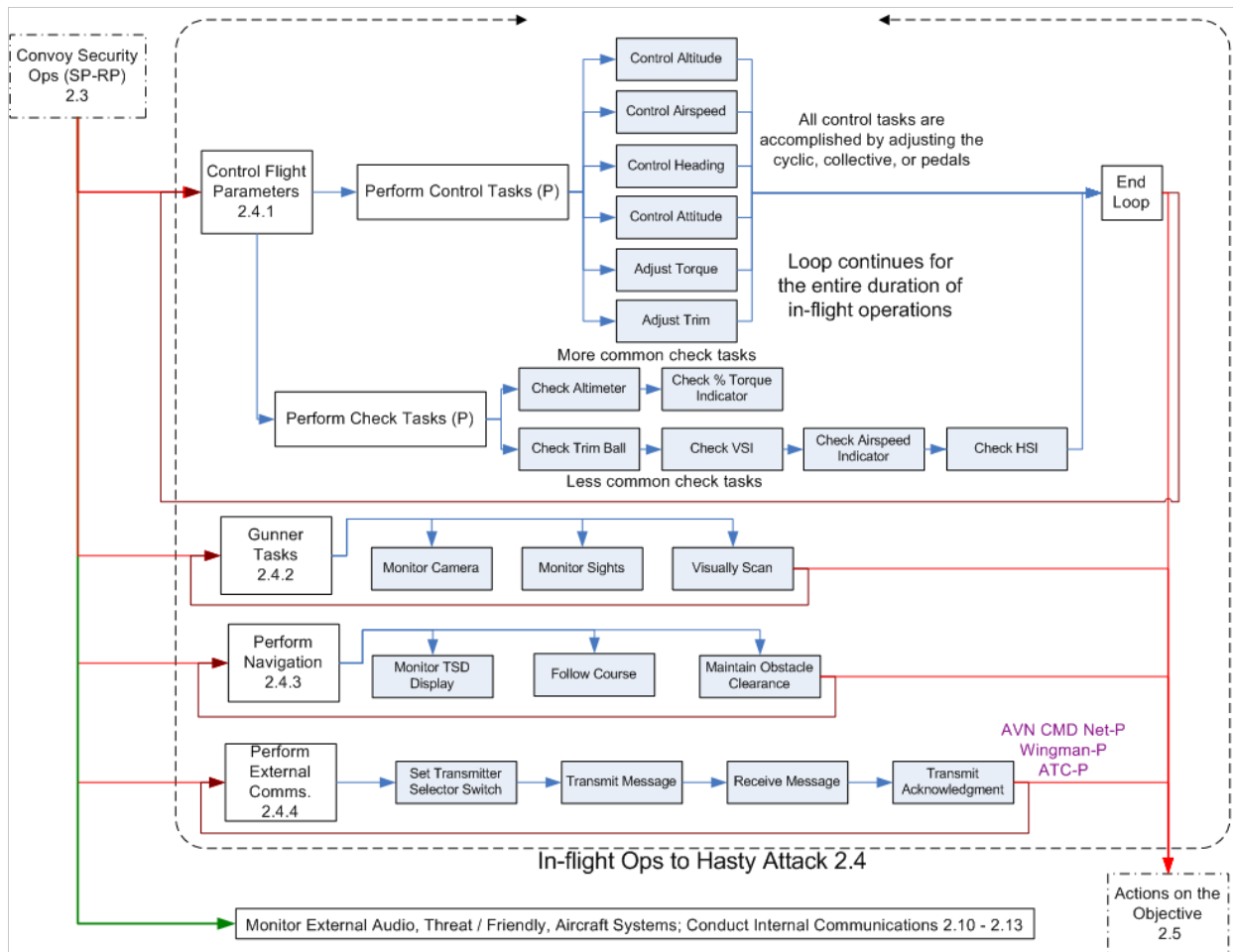


Figure 8: In-flight Ops

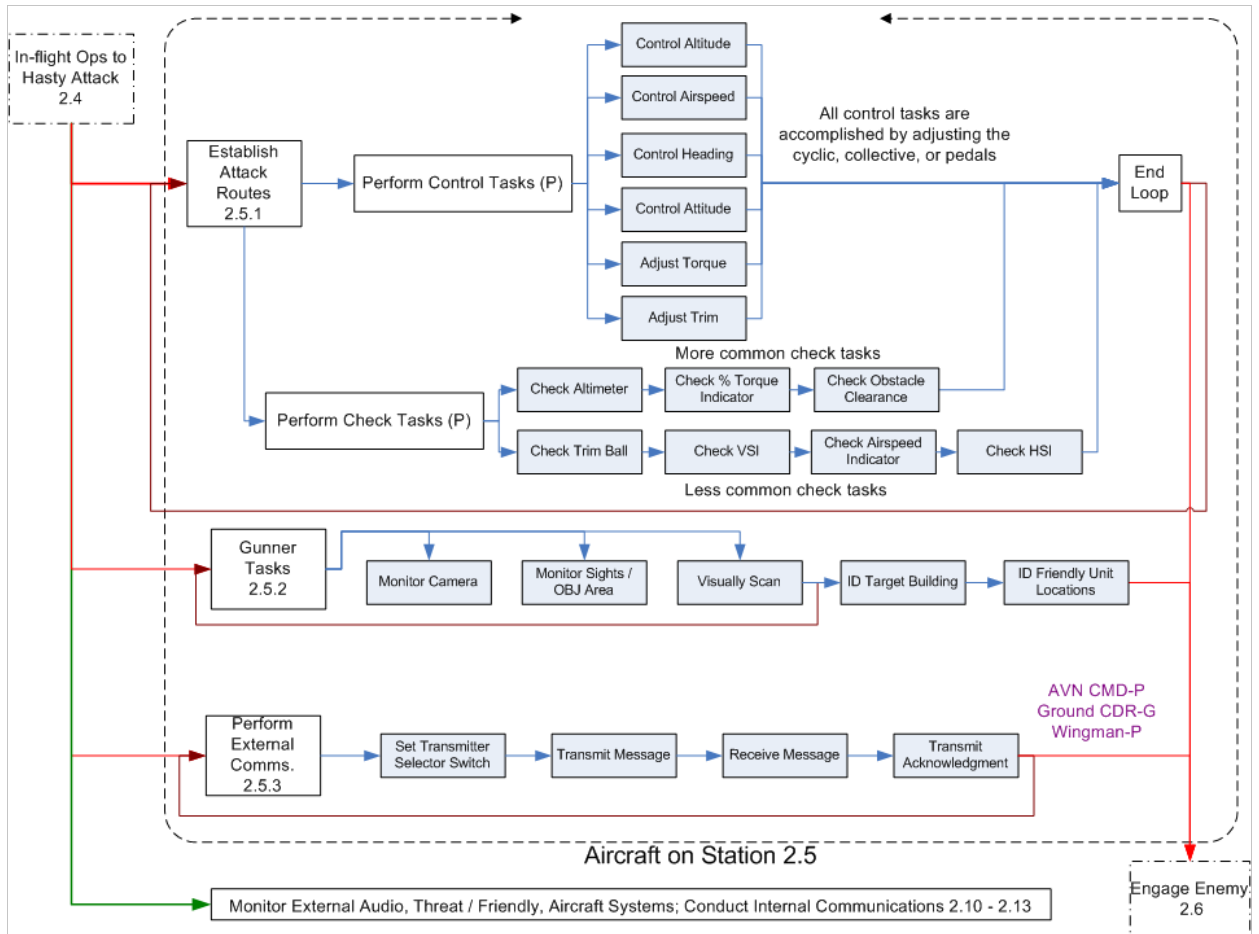


Figure 9: On Station

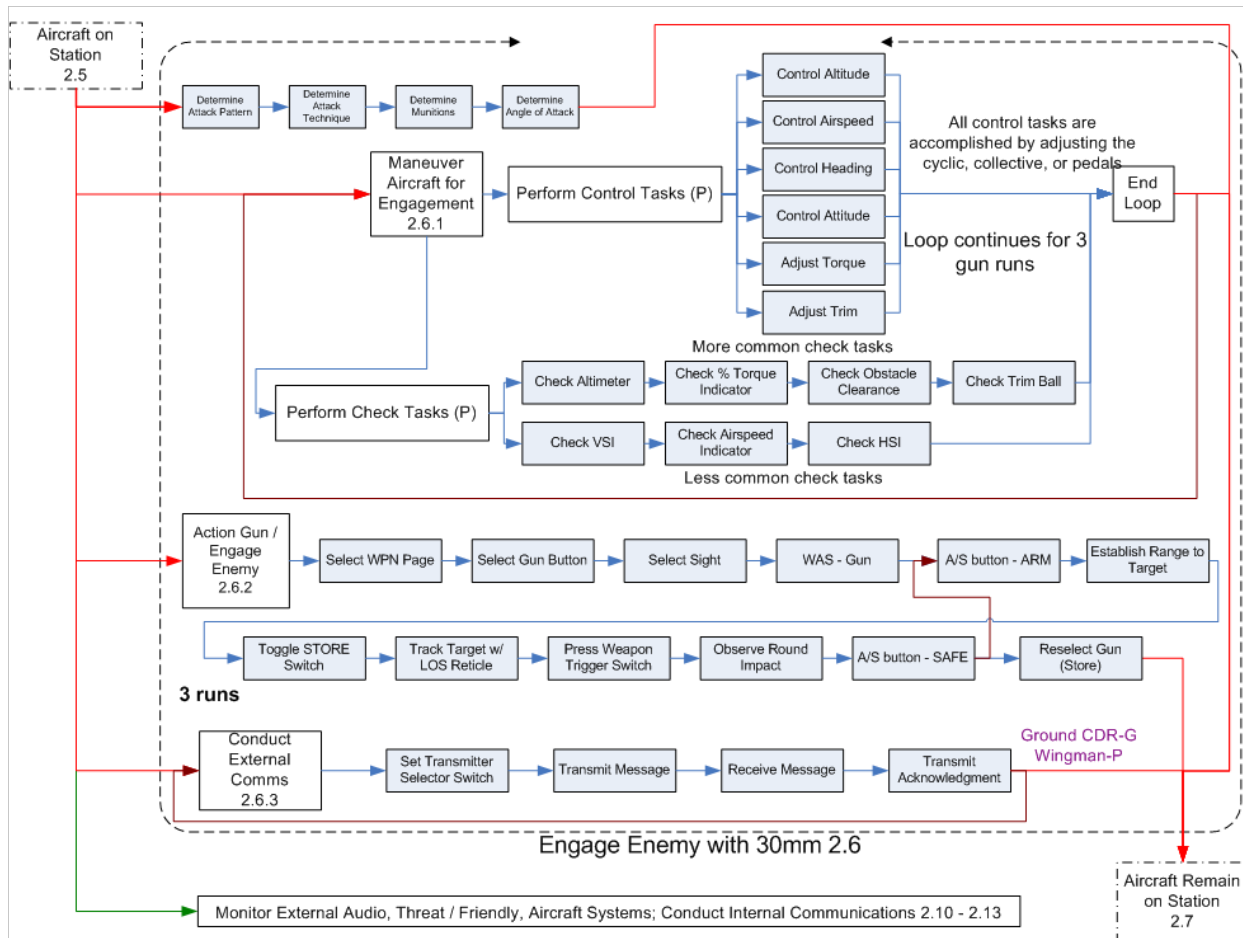


Figure 10: Engage Enemy

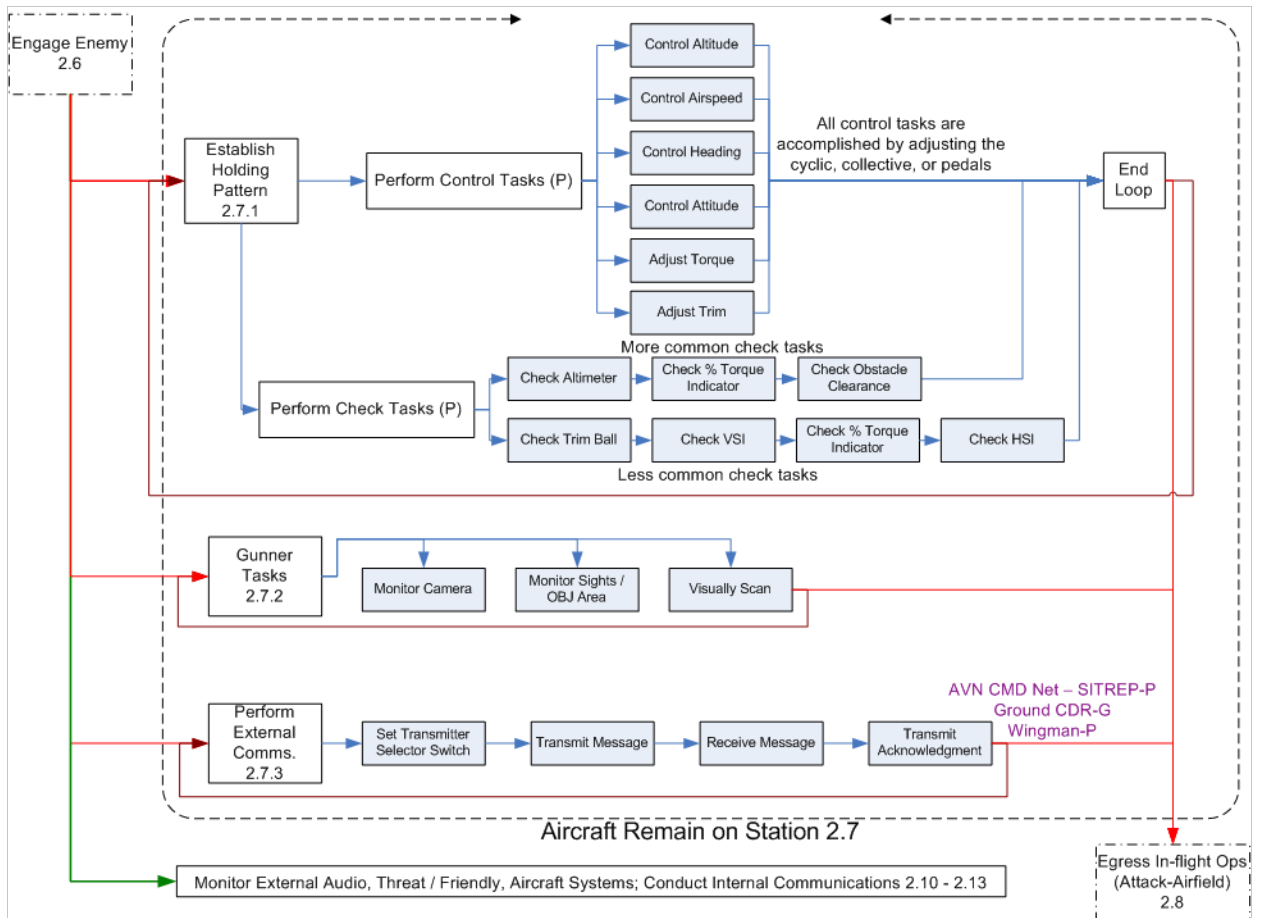


Figure 11: Remain On Station

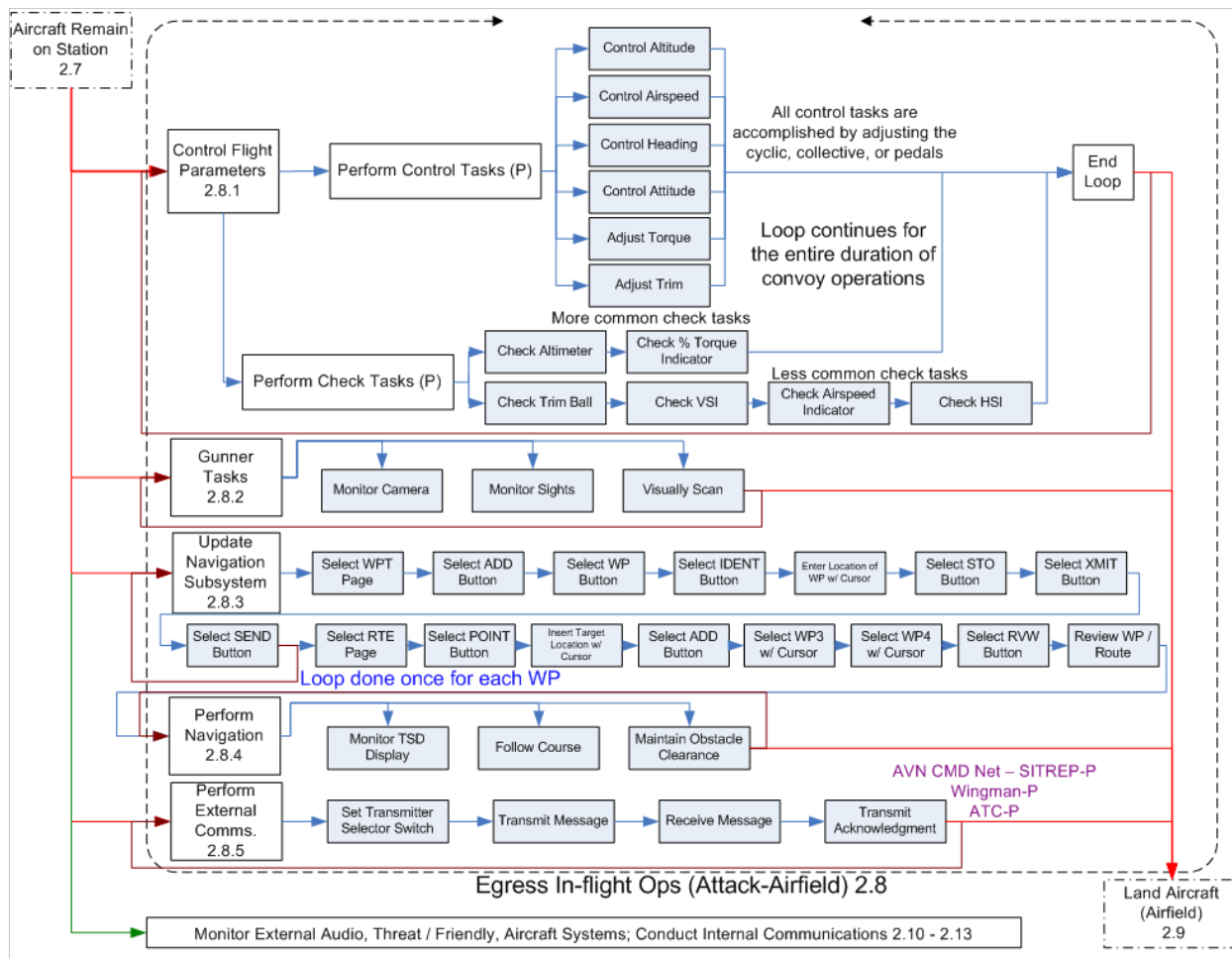


Figure 12: Egress

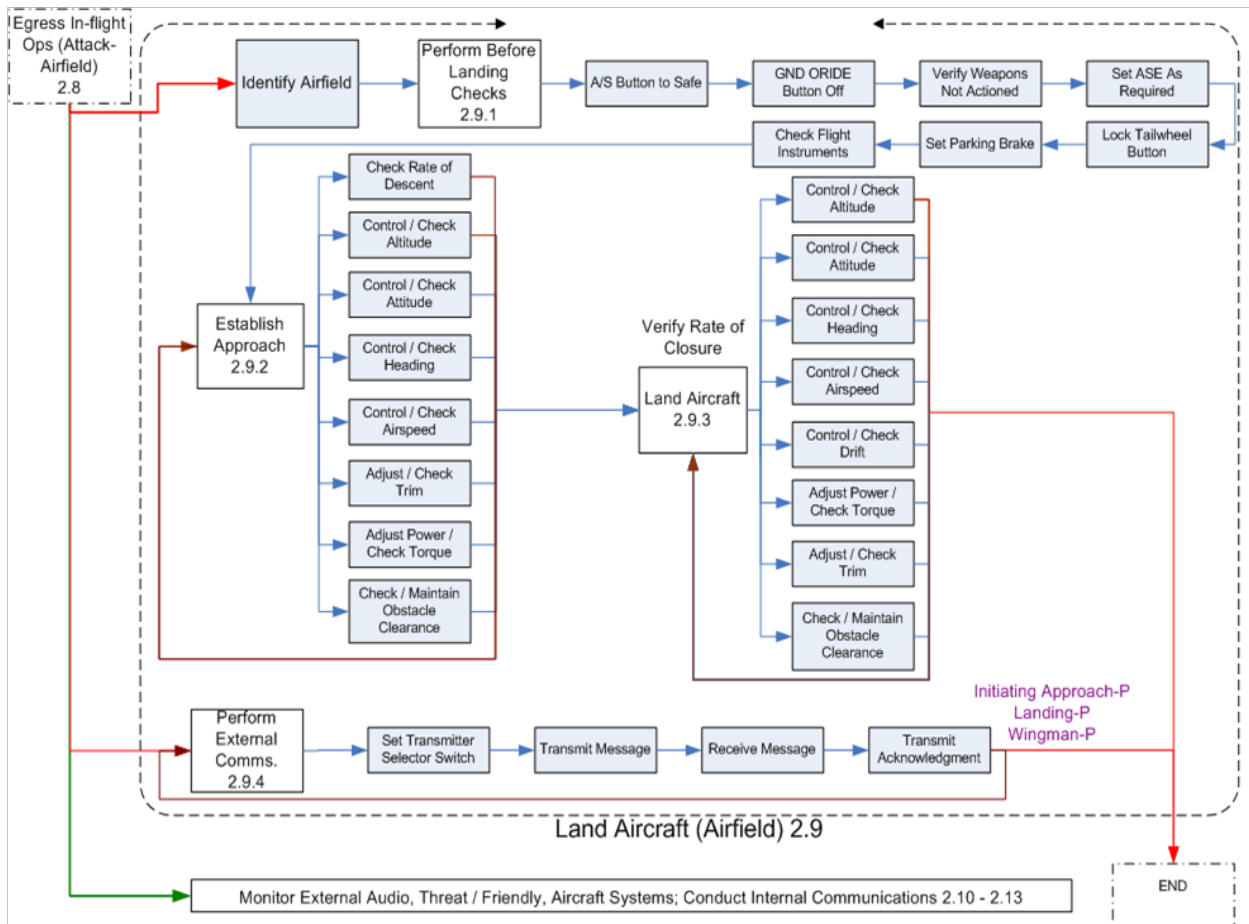


Figure 13: Land

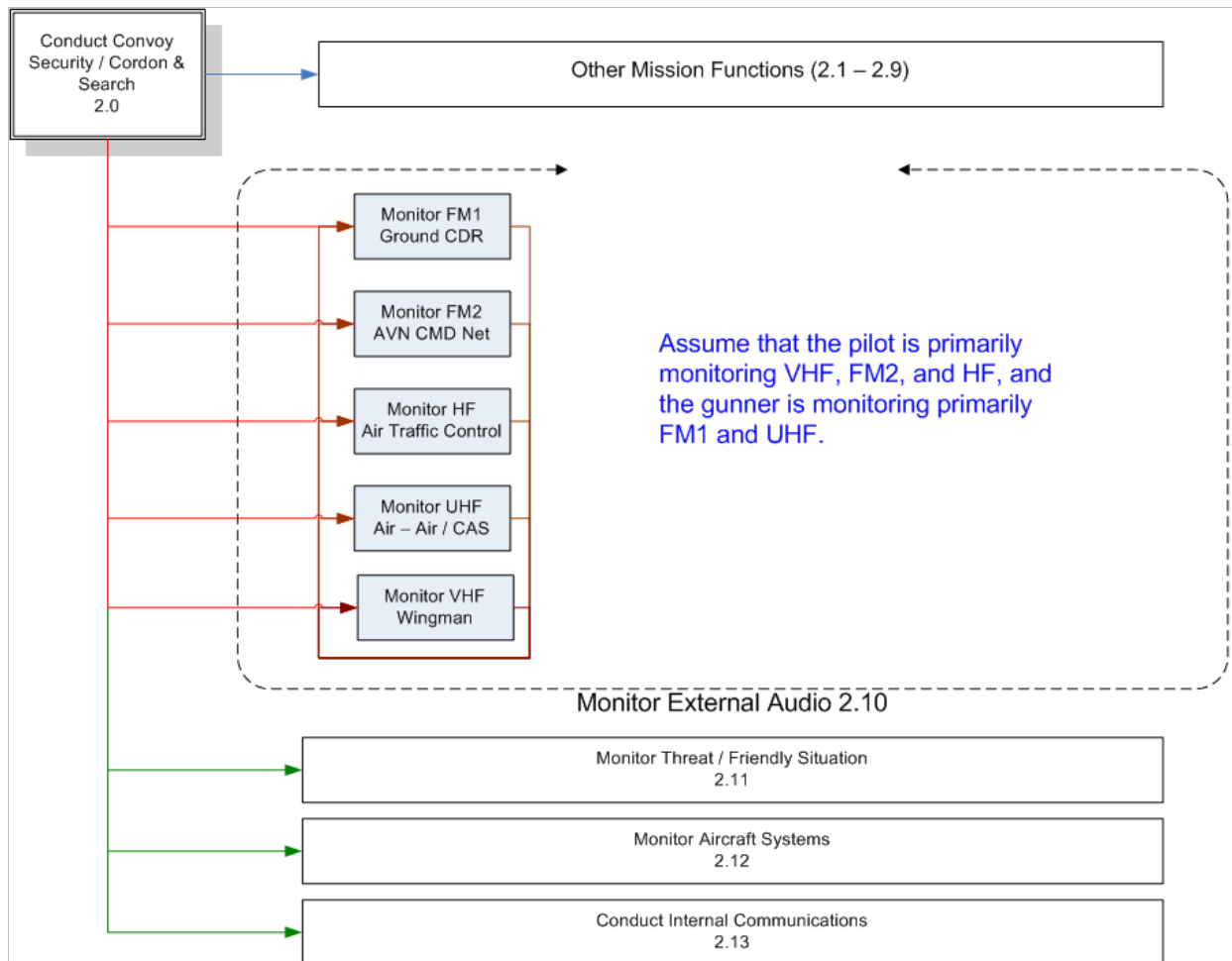


Figure 14: External Audio

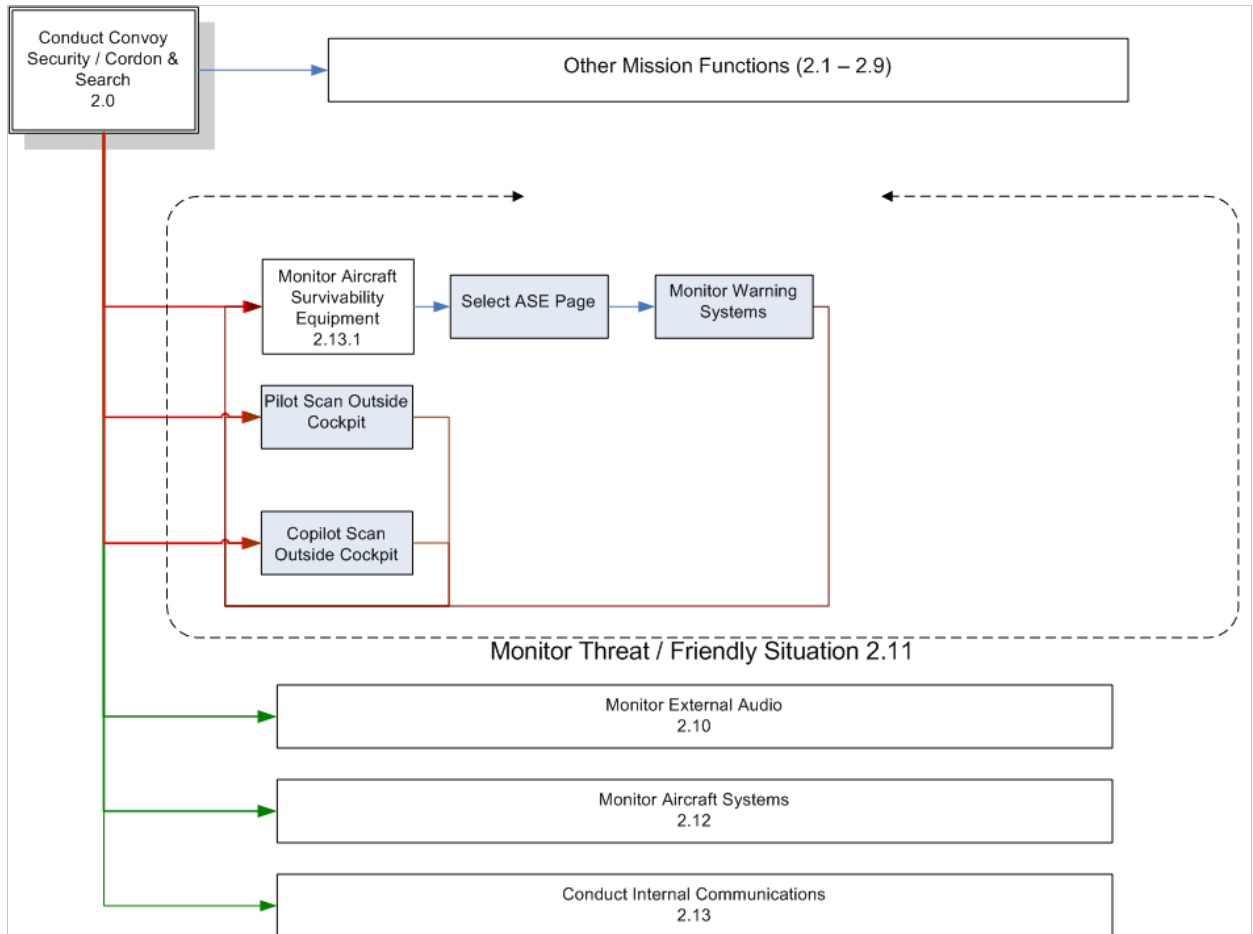


Figure 15: Threat / Friendly Situation

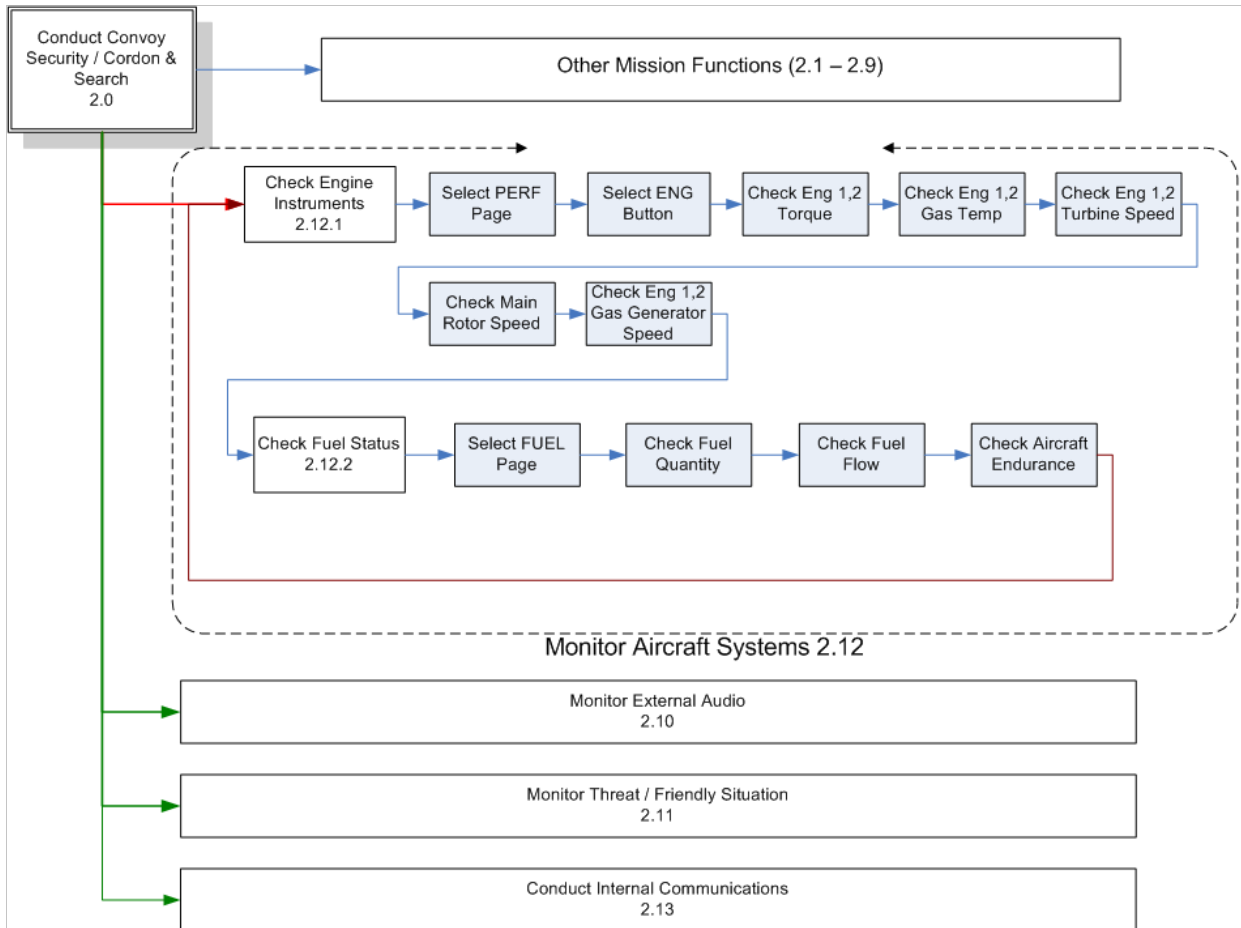


Figure 16: Aircraft Systems

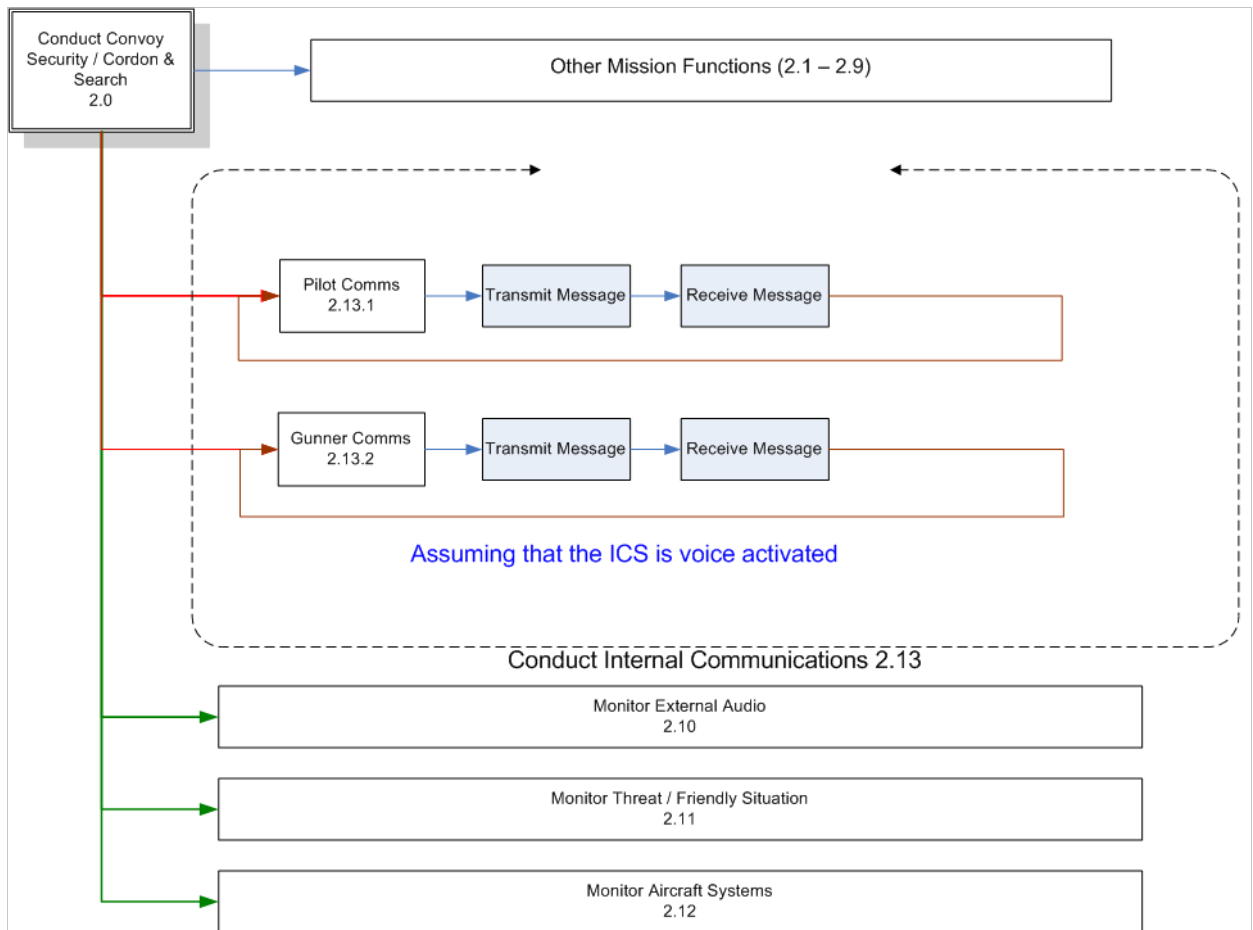


Figure 17: Internal Communication

Appendix C - UH-60 Survey

UH-60: Deliver Internal Payload (Air Assault) Survey

Please answer all questions within the context of the scenario described to you in the role of both P and P* simultaneously for Part 1; answer Part 2 in P or P*.

Part 1: Information Requirements: This part is designed in order to determine a hierarchy of information requirements for pilots at different times throughout a mission.

Section 1 – Aircraft Takeoff

Section 1a – Perform Before Takeoff Checks: Please rank order the following information requirements with 1 being the highest priority information requirement, and 12 being the least. Ties are allowed.

- | | |
|---------------------------------|---|
| ___ Satellite coverage | ___ Infrared countermeasures status |
| ___ Fuel status | ___ Chaff dispenser status |
| ___ Armor panel status | ___ Power lever status |
| ___ Radio status | ___ Status of flight instruments (Eng 1 & 2, Rotor RPM) |
| ___ Crew status | ___ Status of master caution indicator |
| ___ Radar jamming switch status | ___ Transponder status |

Section 1b – Perform Hover: Please rank order the following information requirements with 1 being the highest priority information requirement, and 7 being the least. Ties are allowed.

- | | |
|--|---------------------------------|
| ___ Obstacle location / clearance (including other aircraft) | ___ Drift |
| ___ Altitude | ___ Heading |
| ___ Attitude | ___ % Torque (performance data) |
| ___ Trim | |

Section 1c – Establish Climb: Please rank order the following information requirements with 1 being the highest priority information requirement, and 8 being the least. Ties are allowed.

- | | |
|--------------|--|
| ___ Airspeed | ___ Heading |
| ___ Altitude | ___ Rate of climb |
| ___ Attitude | ___ % Torque |
| ___ Trim | ___ Obstacle location / clearance (including other aircraft) |

Section 2 – In-flight Operations

Section 2a – Establish Level Flight / Control Flight Parameters: Please rank order the following information requirements with 1 being the highest priority information requirement, and 7 being the least. Ties are allowed.

- | | |
|--------------------|--------------|
| ___ Airspeed | ___ % Torque |
| ___ Altitude | ___ Attitude |
| ___ Time (for FBR) | ___ Heading |
| ___ Trim | |

Section 2b – Perform Navigation: Please rank order the following information requirements with 1 being the highest priority information requirement, and 5 being the least. Ties are allowed.

- | | |
|---|---------------------|
| ___ Obstacle location / clearance (including other aircraft) | ___ Heading |
| ___ GPS route information to include current location and waypoints | ___ Map information |
| ___ Groundspeed | |

Section 3 – React to Minor Aircraft Malfunction (#1 & #2 Generator Failure)

Please rank order the following information requirements with 1 being the highest priority information requirement, and 3 being the least. Ties are allowed.

- | | |
|--------------------------------------|---|
| ___ Sequence of emergency procedures | ___ Status of master caution indicator / advisory panel |
| ___ Aircraft systems status | |

Section 4 – Receive FRAGO (Change in LZ)

Please rank order the following information requirements with 1 being the highest priority information requirement, and 6 being the least. Ties are allowed.

- | | |
|-------------------------|------------------------------|
| ___ New RP location | ___ New route |
| ___ Location of new LZ | ___ Wind direction on new LZ |
| ___ New landing heading | ___ Satellite coverage |

Section 5 – React to Enemy Ground Fire (Large caliber, radar guided, anti-aircraft fire)

Please rank order the following information requirements with 1 being the highest priority information requirement, and 11 being the least. Ties are allowed.

- | | |
|--|---|
| ___ Location of enemy / threat | ___ Change in % Torque from evasive maneuvers |
| ___ Obstacle location / clearance (including other aircraft) | ___ Change in Airspeed from evasive maneuvers |
| ___ Change in Altitude from evasive maneuvers | ___ Aircraft location |
| ___ Change in Attitude from evasive maneuvers | ___ Heading to next ACP |
| ___ Change in Heading (90°) from evasive maneuvers | ___ CMWS Warning |
| ___ Status of countermeasure (chaff) dispensing | |

Section 6 – Actions on the Objective / Land Aircraft

Section 6a – Perform Before Landing Checks: Please rank order the following information requirements with 1 being the highest priority information requirement, and 8 being the least. Ties are allowed.

- | | |
|-------------------------------------|-------------------------------------|
| ___ LZ / Airfield location | ___ Radar jamming switch status |
| ___ Tailwheel advisory light status | ___ Infrared countermeasures status |
| ___ Radio status | ___ Chaff dispenser status |
| ___ Crew status | ___ Parking brake status |

Section 6b – Establish / Initiate Approach: Please rank order the following information requirements with 1 being the highest priority information requirement, and 9 being the least. Ties are allowed.

___ Rate of descent	___ Heading
___ Altitude	___ Airspeed
___ Attitude	___ % Torque
___ Drift	___ Trim
___ Obstacle location / clearance (including other aircraft)	

Section 6c – Land / Unload Aircraft: Please rank order the following information requirements with 1 being the highest priority information requirement, and 8 being the least. Ties are allowed.

___ Rate of closure	___ Wind direction
___ Altitude	___ Obstacle location / clearance (including other aircraft)
___ Attitude	___ Unloading complete / incomplete
___ Heading	___ Status of doors

Section 7 – Monitor Aircraft Systems

Please rank order the following information requirements with 1 being the highest priority information requirement, and 6 being the least. Ties are allowed.

___ Engine 1 / Engine 2 RPM	___ Status of caution / advisory panel
___ Rotor RPM	___ Fuel quantity
___ Status of master caution indicator	___ Fuel consumption rate

Section 8 – Internal / External Communications

Please rank order the following information requirements with 1 being the highest priority information requirement, and 5 being the least. Ties are allowed.

___ Comms with ground commander	___ Comms with aircraft in serial
___ Comms with air traffic control	___ Comms on AVN CMD Net
___ Internal communication	

Part 2: Information Overload: This part of the survey is designed to determine in relation to what resource pilots / copilots feel they are overloaded in, and what instrumentation / situations are responsible for the overload. **Choose Pilot / Copilot.**

Section 9 – Resources

Please rank order the following human resources with 1 being the area in which you feel overloaded the most, and 5 being the area with the least overload.

- | | |
|---|------------------------|
| ___ Auditory | ___ Visual |
| ___ Cognitive (Problem Solving / Reasoning) | ___ Gross / Fine motor |
| ___ Speech | |

Section 10 – Auditory Stimuli

Please rank order the following auditory stimulus that occur the most in a scenario described to you, with 1 being the one occurring the most frequently, and 7 being the least frequent.

- | | |
|--|---|
| ___ Radio traffic with ground commander | ___ Radio traffic with aircraft serial |
| ___ Radio traffic with air traffic control | ___ Internal radio traffic between crew / pilot / copilot |
| ___ Aircraft noise | ___ Radio traffic on AVN command net |
| ___ CMWS tones | |

Section 11 – Visual Stimuli

Please rank order the following visual stimulus that occur the most in a scenario described to you, with 1 being the one occurring the most frequently, and 7 being the least frequent.

- | | |
|--------------------------------------|------------------------------------|
| ___ Indicator / warning lights | ___ Gauges / situation indicators |
| ___ Displays | ___ Ground obstacle location |
| ___ Objective area / LZ / Airfield | ___ Enemy / Friendly ground forces |
| ___ Other friendly aircraft location | |

Section 12 – Cognitive Stimuli

Please rank order the following cognitive stimulus that occur the most in a scenario described to you, with 1 being the one occurring the most frequently, and 5 being the least frequent.

- | | |
|-------------------------------|--|
| ___ Map reading | ___ GPS / following set course |
| ___ React to FRAGO / planning | ___ Decision making based on aircraft systems status |
| ___ Calculations | |

Section 13 – Gross / Fine Motor Stimuli

Please rank order the following gross / fine motor stimulus that occur the most in a scenario described to you, with 1 being the one occurring the most frequently, and 5 being the least frequent.

- | | |
|---|--|
| ___ Toggling / Switching / Button pushing | ___ Adjusting cyclic stick |
| ___ Adjusting collective stick | ___ Adjusting directional control pedals |
| ___ Writing | |

Section 14 – Speech Stimuli

Please rank order the following speech stimulus that occur the most in a scenario described to you, with 1 being the one occurring the most frequently, and 4 being the least frequent.

____ Speaking with ground commander

____ Speaking with other aircraft in serial

____ Speaking with air traffic control

____ Speaking internally with crew / copilot / pilot

Part 3: Free Response Section:

Are there any other information requirements that are important to pilots that are not covered in this survey?

Are there any other areas that you feel overloaded in? If so, please explain why.

Can you think of any changes to cockpit design that would reduce workload (i.e., digital gauges, touch screens instead of keyboards, tactile interfaces, etc...)?

Appendix D - AH-64D Survey

AH-64D: Convoy Security / Hasty Attack Survey

Please answer all questions within the context of the scenario described to you in the role of both PLT and CPG for Part 1; answer Part 2 in terms of PLT or CPG.

Part 1: Information Requirements: This part is designed in order to determine a hierarchy of information requirements for pilots at different times throughout a mission.

Section 1 – Aircraft Takeoff

Section 1a – Perform Before Takeoff Checks: Please rank order the following information requirements with 1 being the highest priority information requirement, and 14 being the least. Ties are allowed. Assume all pre-engine / weapons initialization / operational checks are already complete.

- | | |
|--|---|
| ___ Satellite coverage | ___ Status of parking brake |
| ___ Fuel status | ___ ASE Status |
| ___ Status of A/S button | ___ Power lever status |
| ___ Status of radios | ___ Status of flight instruments (Eng 1 & 2, Rotor RPM) |
| ___ Weapons status (actioned / not actioned) | ___ Status of master caution indicator |
| ___ Status of GND ORIDE button | ___ Transponder status |
| ___ Status of tailwheel (lock / unlock) | ___ UFD / EUFD caution status |

Section 1b – Perform Hover: Please rank order the following information requirements with 1 being the highest priority information requirement, and 7 being the least. Ties are allowed.

- | | |
|--|---------------------------------|
| ___ Obstacle location / clearance (including other aircraft) | ___ Drift |
| ___ Altitude | ___ Heading |
| ___ Attitude | ___ % Torque (performance data) |
| ___ Trim | |

Section 1c – Establish Climb: Please rank order the following information requirements with 1 being the highest priority information requirement, and 8 being the least. Ties are allowed.

- | | |
|--------------|--|
| ___ Airspeed | ___ Heading |
| ___ Altitude | ___ Rate of climb |
| ___ Attitude | ___ % Torque |
| ___ Trim | ___ Obstacle location / clearance (including other aircraft) |

Section 2 – In-flight Operations

Section 2a – Control Flight Parameters: Please rank order the following information requirements with 1 being the highest priority information requirement, and 6 being the least. Ties are allowed.

- | | |
|--------------|--------------|
| ___ Airspeed | ___ % Torque |
| ___ Altitude | ___ Attitude |
| ___ Heading | ___ Trim |

Section 2b – Perform Navigation: Please rank order the following information requirements with 1 being the highest priority information requirement, and 4 being the least. Ties are allowed.

___ Obstacle location / clearance (including other aircraft)	___ Heading
___ TSD route information to include current location and waypoints	___ Fuel consumption rate

Section 2c – In-flight CPG Tasks: Please rank order the following information requirements with 1 being the highest priority information requirement, and 4 being the least. Ties are allowed.

___ Camera / video status	___ Video recorder status
___ Weapon system status	___ Sight system status

Section 3 – React to Minor Aircraft Malfunction (Engine 1 Chips)

Please rank order the following information requirements with 1 being the highest priority information requirement, and 5 being the least. Ties are allowed.

___ Sequence of emergency procedures	___ Status of master caution indicator
___ Aircraft system status	___ UFD / EUFD caution status
___ Engine 1 power status	

Section 4 – Receive FRAGO (Change of Mission)

Please rank order the following information requirements with 1 being the highest priority information requirement, and 5 being the least. Ties are allowed.

___ Location of target	___ New route
___ Enemy situation at target	___ WP location / selection
___ Satellite coverage	

Section 5 – Engage Enemy (with 30mm)

Please rank order the following information requirements with 1 being the highest priority information requirement, and 9 being the least. Ties are allowed.

___ Location of enemy / threat	___ Attack pattern / technique
___ Obstacle location / clearance (including other aircraft)	___ Angle of attack
___ Range to target	___ Location of friendly units
___ Weapons status	___ Symbology alignment
___ Location of impacting rounds	

Section 6 – Land Aircraft

Section 6a – Perform Before Landing Checks: Please rank order the following information requirements with 1 being the highest priority information requirement, and 8 being the least. Ties are allowed.

- | | |
|---|--|
| ___ Airfield location | ___ Status of A/S button |
| ___ Status of tailwheel (lock / unlock) | ___ Status of GND ORIDE button |
| ___ Status of radios | ___ Weapons status (actioned / not actioned) |
| ___ ASE status | ___ Status of parking brake |

Section 6b – Establish / Initiate Approach: Please rank order the following information requirements with 1 being the highest priority information requirement, and 9 being the least. Ties are allowed.

- | | |
|--|--------------|
| ___ Rate of descent | ___ Heading |
| ___ Altitude | ___ Airspeed |
| ___ Attitude | ___ % Torque |
| ___ Drift | ___ Trim |
| ___ Obstacle location / clearance (including other aircraft) | |

Section 6c – Land Aircraft: Please rank order the following information requirements with 1 being the highest priority information requirement, and 10 being the least. Ties are allowed.

- | | |
|---------------------|--|
| ___ Rate of closure | ___ Wind direction |
| ___ Altitude | ___ Obstacle location / clearance (including other aircraft) |
| ___ Attitude | ___ Drift |
| ___ Heading | ___ Trim |
| ___ Airspeed | ___ % Torque |

Section 7 – Monitor Aircraft Systems

Please rank order the following information requirements with 1 being the highest priority information requirement, and 9 being the least. Ties are allowed.

- | | |
|---|---|
| ___ Engine 1 / Engine 2 RPM | ___ UFD / EUFD caution status |
| ___ Rotor RPM | ___ Fuel quantity |
| ___ Status of master caution indicator | ___ Fuel flow |
| ___ Aircraft endurance | ___ Engine 1 / Engine 2 gas generator speed |
| ___ Engine 1 / Engine 2 gas temperature | |

Section 8 – Internal / External Communications

Please rank order the following information requirements with 1 being the highest priority information requirement, and 5 being the least. Ties are allowed.

- | | |
|--|----------------------------------|
| ___ Status of comms with ground commander / convoy | ___ Status of comms with wingman |
| ___ Status of comms with air traffic control | ___ Status of comms with AVN CMD |
| ___ Status of internal communication system | |

Part 2: Information Overload: This part of the survey is designed to determine in relation to what resource pilots feel they are overloaded in, and what instrumentation / situations are responsible for the overload. **Choose PLT / CPG.**

Section 9 – Resources

Please rank order the following human resources with 1 being the area in which you feel overloaded the most, and 5 being the area with the least overload.

- | | |
|---|------------------------|
| ___ Auditory | ___ Visual |
| ___ Cognitive (Problem Solving / Reasoning) | ___ Gross / Fine motor |
| ___ Speech | |

Section 10 – Auditory Stimuli

Please rank order the following auditory stimulus that occur the most in a scenario described to you, with 1 being the one occurring the most frequently, and 7 being the least frequent.

- | | |
|--|--|
| ___ Radio traffic with ground commander | ___ Radio traffic with wingman |
| ___ Radio traffic with air traffic control | ___ Internal radio traffic between PLT / CPG |
| ___ General aircraft noise | ___ Radio traffic with AVN CMD |
| ___ Audio Tones from aircraft malfunction | |

Section 11 – Visual Stimuli

Please rank order the following visual stimulus that occur the most in a scenario described to you, with 1 being the one occurring the most frequently, and 8 being the least frequent.

- | | |
|---------------------------------------|------------------------------------|
| ___ Indicator lights | ___ Gauges |
| ___ Displays | ___ Obstacle locations |
| ___ General scanning outside aircraft | ___ Enemy / Friendly ground forces |
| ___ Other friendly aircraft locations | ___ Scanning with sights / camera |

Section 12 – Cognitive Stimuli

Please rank order the following cognitive stimulus that occur the most in a scenario described to you, with 1 being the one occurring the most frequently, and 7 being the least frequent.

- | | |
|---------------------------------------|---|
| ___ Comprehending display information | ___ Following route |
| ___ React to FRAGO / planning | ___ Decision making based on aircraft systems status |
| ___ Calculations | ___ Determining attack parameters (angle, pattern, etc) |
| ___ Processing sensory input | |

Section 13 – Gross / Fine Motor Stimuli

Please rank order the following gross / fine motor stimulus that occur the most in a scenario described to you, with 1 being the one occurring the most frequently, and 5 being the least frequent.

- | | |
|---|--|
| ___ Toggling / Switching / Button pushing | ___ Adjusting cyclic stick |
| ___ Adjusting collective stick | ___ Adjusting directional control pedals |
| ___ Tracking targets through sights | |

Section 14 – Speech Stimuli

Please rank order the following speech stimulus that occur the most in a scenario described to you, with 1 being the one occurring the most frequently, and 5 being the least frequent.

____ Speaking with ground commander

____ Speaking with air traffic control

____ Speaking with AVN CMD

____ Speaking with wingman

____ Speaking internally with PLT / CPG

Part 3: Free Response Section:

Are there any other information requirements that are important to pilots that are not covered in this survey?

Are there any other areas that you feel overloaded in? If so, please explain why.

Can you think of any changes to cockpit design that would reduce workload (i.e., touch screens instead of keys, etc...)?

Appendix E - UH-60 Survey Raw Data

ID	Month 1: Week 1										Month 1: Week 2										Month 1: Week 3										Month 1: Week 4										Month 1: Week 5										Month 1: Week 6										Month 1: Week 7										Month 1: Week 8										Month 1: Week 9										Month 1: Week 10										Month 1: Week 11										Month 1: Week 12										Month 1: Week 13										Month 1: Week 14										Month 1: Week 15										Month 1: Week 16										Month 1: Week 17										Month 1: Week 18										Month 1: Week 19										Month 1: Week 20										Month 1: Week 21										Month 1: Week 22										Month 1: Week 23										Month 1: Week 24										Month 1: Week 25										Month 1: Week 26										Month 1: Week 27										Month 1: Week 28										Month 1: Week 29										Month 1: Week 30										Month 1: Week 31										Month 1: Week 32										Month 1: Week 33										Month 1: Week 34										Month 1: Week 35										Month 1: Week 36										Month 1: Week 37										Month 1: Week 38										Month 1: Week 39										Month 1: Week 40										Month 1: Week 41										Month 1: Week 42										Month 1: Week 43										Month 1: Week 44										Month 1: Week 45										Month 1: Week 46										Month 1: Week 47										Month 1: Week 48										Month 1: Week 49										Month 1: Week 50										Month 1: Week 51										Month 1: Week 52										Month 1: Week 53										Month 1: Week 54										Month 1: Week 55										Month 1: Week 56										Month 1: Week 57										Month 1: Week 58										Month 1: Week 59										Month 1: Week 60										Month 1: Week 61										Month 1: Week 62										Month 1: Week 63										Month 1: Week 64										Month 1: Week 65										Month 1: Week 66										Month 1: Week 67										Month 1: Week 68										Month 1: Week 69										Month 1: Week 70										Month 1: Week 71										Month 1: Week 72										Month 1: Week 73										Month 1: Week 74										Month 1: Week 75										Month 1: Week 76										Month 1: Week 77										Month 1: Week 78										Month 1: Week 79										Month 1: Week 80										Month 1: Week 81										Month 1: Week 82										Month 1: Week 83										Month 1: Week 84										Month 1: Week 85										Month 1: Week 86										Month 1: Week 87										Month 1: Week 88										Month 1: Week 89										Month 1: Week 90										Month 1: Week 91										Month 1: Week 92										Month 1: Week 93										Month 1: Week 94										Month 1: Week 95										Month 1: Week 96										Month 1: Week 97										Month 1: Week 98										Month 1: Week 99										Month 1: Week 100										Month 1: Week 101										Month 1: Week 102										Month 1: Week 103										Month 1: Week 104										Month 1: Week 105										Month 1: Week 106										Month 1: Week 107										Month 1: Week 108										Month 1: Week 109										Month 1: Week 110										Month 1: Week 111										Month 1: Week 112										Month 1: Week 113										Month 1: Week 114										Month 1: 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	Pilot Position	Resources			Auditory Stimuli						Visual Stimuli						Cognitive Stimuli				Gross/Fine Motor Stimuli					Speech Stimuli								
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2	CP	1	2	3	3		5	2	7	6	2	1	2	5	5	4	1	5	1	1	3	1	5	3	2	4	1	5	1	1	4	3	2	1
3	CP	1	2	5	4	3	6	5	1	7	4	3	2	4	7	3	1	4	2	6	4	1	5	3	2	1	4	2	3	5	4	3	1	2
4	CP	1	2	3	5	4	6	5	1	3	3	2	7	5	4	7	1	3	2	6	4	3	4	1	2	3	1	5	1	4	4	3	2	1
5	CP	1	3	4	5	2	5	6	1	7	3	2	4	1	1	6	5	1	4	7	3	2	5	1	4	1	3	2	3	4	3	2	1	1
6	CP	3	2	1	5	4	7	4	6	5	2	1	3	2	3	4	7	1	5	6	4	5	1	3	2	4	3	5	1	2	4	3	2	1
7	CP	2	1	3	5	4	3	6	7	5	4	1	2	7	6	5	3	2	1	4	3	1	5	4	2	1	4	2	3	5	3	4	2	1
8	CP	2	1	3	4	5	4	5	1	6	3	2	7	3	1	4	5	2	6	7	1	1	4	5	1	4	1	5	1	1	3	4	2	1
9	CP	2	1	4	5	3	6	7	1	5	3	2	4	7	1	6	2	3	4	5	2	3	5	1	4	3	2	4	1	5	3	4	2	1
10	CP	1	2	4	3	5	5	3	7	6	2	1	4	6	7	2	3	4	1	5	2	4	3	2	1	4	1	5	2	3	4	3	2	1
11	CP	2	1	3	5	4	5	6	1	7	3	2	4	7	1	5	3	2	6	4	2	5	3	1	4	1	3	5	2	4	3	4	2	1
12	P	2	4	1	5	3	5	6	1	7	3	2	4	4	2	7	1	3	6	5	3	5	2	1	4	5	2	4	1	3	4	3	2	1
13	P	1	2	3	4	5	5	3	4	7	2	1	5	5	2	6	4	2	1	7	1	4	1	4	3	2	3	1	3	3	3	2	1	1
14	P	1	3	3	3	2	6	7	3	4	2	1	5	3	5	6	2	1	4	7	1	4	2	3	5	1	4	2	3	5	4	3	2	1
15	P	1	2	3	4	4	4	5	7	6	3	1	2	5	1	7	4	2	6	3	4	1	3	5	2	1	4	2	3	5	3	4	2	1
16	P	2	3	1	5	4	5	4	1	7	3	2	5	7	2	6	5	1	3	4	3	2	4	1	5	2	3	1	4	5	4	3	2	1
17	P	3	5	4	2	1	5	4	7	6	2	1	3	5	3	6	1	2	3	7	4	1	2	5	2	1	4	2	3	5	4	3	2	1
18	P	1	2	3	4	5	7	6	2	3	4	1	5	1	2	6	3	4	5	7	4	3	5	2	1	4	2	5	1	3	4	3	2	1
19	P	4	3	2	1	5	2	7	6	5	3	1	4	3	7	1	2	4	6	5	3	1	5	4	2	3	2	5	1	4	4	3	2	1
20	P	2	1	4	3	5	4	5	6	7	2	3	1	3	4	5	1	6	2	7	3	1	5	4	2	1	4	2	3	5	3	4	1	2

Figure 2: UH-60, Part 2, Raw Data

Appendix F - AH-64D Survey Raw Data

No.	Name	Personal Information			Academic Background			Professional Experience			Research Interests			Publications			Awards & Honors			References		
		First Name	Last Name	Date of Birth	Undergraduate Institution	Graduate Institution	Current Institution	Position	Start Date	End Date	Field	Topic	Year	Journal	Volume	Page	Year	Organization	Year	Ref. 1	Ref. 2	Ref. 3
1	John Doe	John	Doe	1985-01-15	University of California, Berkeley	Stanford University	Stanford University	Assistant Professor	2010-01-01	2015-12-31	Computer Science	Machine Learning	2012	Journal of Machine Learning Research	13	1-10	2013	ACM SIGKDD Conference	2014	Dr. Jane Smith	Dr. Michael Chen	Dr. Emily White
2	Jane Smith	Jane	Smith	1980-03-22	MIT	MIT	MIT	Senior Researcher	2008-01-01	2010-12-31	Physics	Quantum Mechanics	2009	Physical Review Letters	97	1-4	2010	APS March Meeting	2011	Dr. Robert Brown	Dr. Lisa Green	Dr. David Black
3	Michael Chen	Michael	Chen	1978-07-10	Harvard University	Harvard University	Harvard University	Postdoctoral Fellow	2005-01-01	2007-12-31	Biology	Genetics	2006	Nature	441	1-3	2007	AAAS Annual Meeting	2008	Dr. Susan Gold	Dr. James Taylor	Dr. Karen Hill
4	Emily White	Emily	White	1982-11-05	Yale University	Yale University	Yale University	Graduate Student	2003-01-01	2005-12-31	Chemistry	Organic Chemistry	2004	Journal of Organic Chemistry	69	1-2	2005	ACS National Meeting	2006	Dr. Mark Davis	Dr. Rachel King	Dr. Thomas Lee
5	Robert Brown	Robert	Brown	1975-04-18	University of Texas at Austin	University of Texas at Austin	University of Texas at Austin	Associate Professor	2001-01-01	2003-12-31	Mathematics	Algebra	2002	Journal of Algebra	253	1-5	2003	AMS Special Session	2004	Dr. Andrew Clark	Dr. Sophia Lewis	Dr. Benjamin Hall
6	Lisa Green	Lisa	Green	1983-09-01	University of Michigan	University of Michigan	University of Michigan	Research Assistant	2006-01-01	2008-12-31	Psychology	Cognitive Psychology	2007	Journal of Experimental Psychology	135	1-6	2008	APA Convention	2009	Dr. Christopher Adams	Dr. Victoria Baker	Dr. Gregory Carter
7	David Black	David	Black	1979-12-03	University of Wisconsin-Madison	University of Wisconsin-Madison	University of Wisconsin-Madison	Visiting Scholar	2004-01-01	2006-12-31	History	World History	2005	American Historical Review	115	1-7	2006	History of Science Society Meeting	2007	Dr. Elizabeth Evans	Dr. Daniel Foster	Dr. Hannah Gibson
8	Susan Gold	Susan	Gold	1981-06-12	University of Illinois at Urbana-Champaign	University of Illinois at Urbana-Champaign	University of Illinois at Urbana-Champaign	Graduate Student	2002-01-01	2004-12-31	Engineering	Electrical Engineering	2003	IEEE Transactions on Circuits and Systems	50	1-8	2004	IEEE Conference on Decision and Control	2005	Dr. Frank Harris	Dr. Grace Ivers	Dr. Henry Jones
9	James Taylor	James	Taylor	1976-02-28	University of Pennsylvania	University of Pennsylvania	University of Pennsylvania	Postdoctoral Fellow	2003-01-01	2005-12-31	Law	Constitutional Law	2004	Journal of Law and Society Review	38	1-9	2005	Law and Society Association Meeting	2006	Dr. Irene Kelly	Dr. Jack Lambert	Dr. Kelly Martin
10	Karen Hill	Karen	Hill	1984-08-14	University of Washington	University of Washington	University of Washington	Research Assistant	2007-01-01	2009-12-31	Environmental Science	Climate Change	2008	Environmental Science & Technology	42	1-10	2009	AGU Fall Meeting	2010	Dr. Leo Nelson	Dr. Mia Ortiz	Dr. Noah Parker
11	Mark Davis	Mark	Davis	1977-05-07	University of California, San Diego	University of California, San Diego	University of California, San Diego	Associate Professor	2000-01-01	2002-12-31	Medicine	Neurology	2001	Annals of Neurology	50	1-4	2002	Neurology Society Meeting	2003	Dr. Olivia Quinn	Dr. Peter Ramirez	Dr. Quinn Santos
12	Rachel King	Rachel	King	1986-10-20	University of Texas at Dallas	University of Texas at Dallas	University of Texas at Dallas	Graduate Student	2004-01-01	2006-12-31	Business	Marketing	2005	Journal of Marketing Research	42	1-5	2006	AMA Meeting	2007	Dr. Ryan Thomas	Dr. Sarah Underwood	Dr. Victor Vance
13	Thomas Lee	Thomas	Lee	1974-03-09	University of Minnesota	University of Minnesota	University of Minnesota	Visiting Scholar	2002-01-01	2004-12-31	Art History	Modernism	2003	Journal of American Studies	37	1-6	2004	Art History Society Meeting	2005	Dr. Wendy Walker	Dr. Xavier Young	Dr. Zoe Ziegler
14	Andrew Clark	Andrew	Clark	1980-11-25	University of Colorado Boulder	University of Colorado Boulder	University of Colorado Boulder	Postdoctoral Fellow	2005-01-01	2007-12-31	Geology	Plate Tectonics	2006	Journal of Geophysical Research	111	1-7	2007	AGU Fall Meeting	2008	Dr. Adam Bell	Dr. Brenda Boyd	Dr. Charles Boyd
15	Sophia Lewis	Sophia	Lewis	1982-04-11	University of Arizona	University of Arizona	University of Arizona	Graduate Student	2003-01-01	2005-12-31	Anthropology	Archaeology	2004	Journal of Archaeological Science	31	1-8	2005	AAAS Annual Meeting	2006	Dr. Diana Boyd	Dr. Eugene Boyd	Dr. Fiona Boyd
16	Benjamin Hall	Benjamin	Hall	1978-09-03	University of New York at Albany	University of New York at Albany	University of New York at Albany	Associate Professor	2001-01-01	2003-12-31	Political Science	International Relations	2002	Journal of International Studies	29	1-9	2003	International Studies Association Meeting	2004	Dr. George Boyd	Dr. Helen Boyd	

Figure 3: AH-64D, Part 1, Raw Data

		Resources				Auditory Stimuli				Visual Stimuli				Cognitive Stimuli				Gross/Fine Motor Stimuli				Speech Stimuli																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
Pilot	Position	Auditory	Cognitive	Speech	Visual																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														

Figure 4: AH-64D, Part 2, Raw Data

Appendix G - Free Response Section Results

Part 3: Free Response Survey Results

Question 1: Are there any other information requirements that are important to pilots that are not covered in this survey?

- “Weapons ranges vs. aircraft range to the target area limitations.” (A)
- “Weather is an important variable that must be considered. Decreased visibility and ceiling increase pilot’s workload significantly.” (A)
- “New LZ security. For most of this mission, height above ground level is more important than altitude.”
- “Situational awareness of entire mission is important for a serial AMC. This allows for anticipation of AVN TF CDR’s decisions, and allows serial AMC to make decisions based on mission profile.”
- “Status of passengers / equipment, weapons, and oil pressure / temperature readings.”
- “Weather problems and crew rest issues.”
- “Weather data. We should be able to get weather data via satellite onto a screen over our moving map.”
- “Surface conditions on LZ to include hazardous debris and brown / white-out conditions.”

Question 2: Are there any other areas that you feel overloaded in? If so, please explain why.

- “Remembering / processing friendly positions vs. danger close parameters.” (A)
- “Night flying is exponentially more difficult than daytime flying as reliance on visual stimuli changes dramatically. All other tasks, are therefore more difficult to complete.” (A)
- “Switching radios and frequencies. The pilot with both hands on the controls must often direct the CPG to change radio frequencies.” (A)
- “Changing radio frequencies and making radio calls in the dark. In air adjustment to route for new LZ. Avoiding gun fire and aircraft in my serial at the same time. Regrouping the flight as a serial.”
- “The Execution Checklist is a mission status report that the serial AMC must use. The AMC calls off completed tasks such as RP or inbound by calling off pre-assigned code words that are written on the checklist.”
- “Auditory is by far the most overloaded component in air operations.”
- “Maintaining rotor disk separation from other helicopters in the serial (in-flight and landing).”
- “Combination of lack of sleep and task saturation.”
- “ALSE equipment. After long flights I often get “hot spots” where the helmet begins to hurt my head or it doesn’t block enough noise. Also, the vest is extremely heavy and bulky, and gets in the way of freely moving around the cockpit.”
- “Blue Force tracking requirements. Environmental factors (too hot / cold, brown-out landings, mountains) all add stimuli and increase workload. Competence of the other pilot, since if they are lacking competence my workload goes up. A by-product of the enemy ground fire would have been an in-flight link-up, which is a high stress event.”

- “Maintaining adequate separation within serial and tracking mission on air movement table.”

Question 3: Can you think of any changes to cockpit design that would reduce workload?

- “Allowing AVN CMD cell to send / e-mail targets or waypoints directly to the crew so we do not have to input them manually.” (A)
- “Lighter helmets / NVG’s and a wireless connection between the helmet and comms / night vision system would help.” (A)
- “More radio functionality displayed on screens.” (A)
- “Pre loading radio frequencies “active” and “standby”. Moving maps with graphics. Displays providing generator failure emergency procedures.”
- “Moving map displays, display of fuel burn rate, memory foam seat cushions, voice activated intercom.”
- “Glass cockpits.”
- “Consolidation of radios with simpler / standard displays and interfaces.”
- “Better HUD’s, autofocus NVG’s, terrain following radar, and auto-hover (basically lots of expensive stuff).”
- “UH-60’s need dual VORs for instrument flight.”
- “Digital displays for pilots and crew chiefs. The crew chiefs greatly assist in reducing workload by monitoring instruments, fuel consumption, etc... If they had a digital display, they could offer even more assistance.”
- “Altitude hold.”
- “Scroll through menu options on a MFD that can be selected via button on the cyclic or collective. MFD’s, as digital gauges are easier to read at night than analog. Touch screens while nice and user friendly, would direct attention inside the aircraft for too long.”
- “The UH-60 needs a fuel flow rate meter that links to the fuel in the tanks and gives an estimated time before burn-out. This is easy to do manually, but when in flight and trying to make decisions for the other aircraft in the serial, it is just faster to have it immediately available. Moving map displays that are easily programmable / loadable via thumb-drive with pre-planned route data integrated with blue force tracker. Available route data should be easy to read including time to the next ACP and ETA to destination.”
- “Mission information displayed in cockpit (virtual map with aircraft locations, LZ’s, PZ’s, etc...).”

Note: (A) indicates response from an Apache pilot, all other are Blackhawk pilots.

Appendix H - IMPRINT Resource Scale Values

Resource	Value	Descriptor
Auditory	1.0	Detect / Register Sound
	2.0	Orient to Sound (General)
	4.2	Orient to Sound (Selective)
	4.3	Verify Auditory Feedback
	3.0	Interpret Semantic Content, Simple
	6.0	Interpret Semantic Content, Complex
	6.6	Discriminate Sound Characteristics
	7.0	Interpret Sound Patterns
Cognitive	1.0	Automatic (Simple Association)
	1.2	Alternative Selection
	4.6	Evaluation / Judgment (Single Aspect)
	5.3	Encoding / Decoding, Recall
	6.8	Evaluation / Judgment (Several Aspects)
	7.0	Estimation, Calculation, Conversion
	5.0	Rehearsal
Fine Motor	2.2	Discrete Actuation
	2.6	Continuous Adjustive
	4.6	Manual
	5.5	Discrete Adjustment
	6.5	Symbolic Production
	7.0	Serial Discrete Manipulation
Speech	2.0	Simple (1-2 Words)
	4.0	Complex (Sentence)
Visual	5.0	Visually Register / Detect
	7.0	Visually Discriminate
	5.0	Visually Inspect / Check
	5.0	Visually Locate / Align
	5.4	Visually Track / Follow
	7.0	Visually Scan / Search, Monitor
Tactile	1.0	Alerting
	2.0	Simple Discrimination
	4.0	Complex Symbolic Information

Figure 5: IMPRINT Resource Scale Values

**Appendix I - IMPRINT Resource Assignment Values for Current
UH-60**

Air Assault Resource Assignment Values for Current Cockpit							
Task	Primary	Est. Time	Audio	Cognitive	Fine Motor	Speech	Visual
Acknowledge FRAGO	Copilot	10	0.0	5.3	0.0	4.0	0.0
Adjust Power	Pilot	1	0.0	4.6	2.6	0.0	0.0
Adjust Trim	Pilot	1	0.0	4.6	2.6	0.0	0.0
Check Airspeed Indicator	Pilot	2	0.0	4.6	0.0	0.0	5.0
Check Altimeter	Pilot	2	0.0	4.6	0.0	0.0	5.0
Check Arm or Panel	Pilot	1	0.0	1.0	0.0	0.0	5.0
Check Crew (Visual)	Copilot	4	0.0	1.2	0.0	0.0	5.0
Check Doors	Copilot	5	0.0	1.2	0.0	0.0	5.0
Check Drift	Pilot	4	0.0	6.8	0.0	0.0	7.0
Check Engine1 RPM	Copilot	1	0.0	4.6	0.0	0.0	5.0
Check Engine2 RPM	Copilot	1	0.0	4.6	0.0	0.0	5.0
Check Flight Instruments	Pilot	7	0.0	4.6	0.0	0.0	7.0
Check Fuel Quantity Indicator	Both	2	0.0	4.6	0.0	0.0	5.0
Check Groundspeed	Copilot	2	0.0	4.6	0.0	0.0	5.0
Check Heading Indicator	Pilot	2	0.0	4.6	0.0	0.0	5.0
Check Master Caution / Advisory Panel	Copilot	2	0.0	6.8	0.0	0.0	5.0
Check Master Caution Indicator	Copilot	1	0.0	1.0	0.0	0.0	1.0
Check Obstacle Clearance	Copilot / Pilot	4	0.0	6.8	0.0	0.0	7.0
Check Parking Break	Copilot	2	0.0	1.2	0.0	0.0	5.0
Check Power Levers	Pilot	2	0.0	1.2	5.5	0.0	5.0
Check Radios (Visual)	Copilot	7	0.0	5.3	2.2	0.0	5.0
Check Rotor RPM	Copilot	1	0.0	4.6	0.0	0.0	5.0
Check Tailwheel Advisory Light	Copilot	1	0.0	1.2	0.0	0.0	5.0
Check Torque Indicator	Pilot	2	0.0	4.6	0.0	0.0	5.0
Check Transponder	Copilot	1	0.0	1.0	0.0	0.0	5.0
Check Trim Ball	Pilot	2	0.0	4.6	0.0	0.0	5.0
Check VSI	Pilot	2	0.0	4.6	0.0	0.0	5.0
Compute Consumption Rate	Copilot	8	0.0	7.0	6.5	0.0	5.0
Control Airspeed	Pilot	3	0.0	4.6	2.6	0.0	0.0
Control Altitude	Pilot	1	0.0	4.6	2.6	0.0	0.0
Control Attitude	Pilot	1	0.0	4.6	2.6	0.0	0.0
Control Drift	Pilot	1	0.0	4.6	2.6	0.0	0.0
Control Heading	Pilot	1	0.0	4.6	2.6	0.0	0.0
Copilot Sector Scan	Copilot	4	0.0	6.8	0.0	0.0	7.0
Detect #1, 2 Caution Lights	Copilot / Pilot	1	0.0	6.8	0.0	0.0	5.0
Depress Floor Handmike Switch (CP)	Copilot	1	0.0	1.2	2.2	0.0	0.0
Depress Floor Handmike Switch (P)	Pilot	1	0.0	1.2	2.2	0.0	0.0
Detect Caution Lights Still On	Copilot / Pilot	1	0.0	1.0	0.0	0.0	5.0
Detect CMWS Warning	Copilot	1	1.0	1.0	0.0	0.0	5.0
Determine Enemy Location	Copilot	5	0.0	6.8	0.0	0.0	5.4
Determine Heading to ACPB	Copilot	3	0.0	6.8	0.0	0.0	5.0
Determine Landing Heading	Copilot	5	0.0	7.0	0.0	0.0	5.0
Determine Location	Copilot	5	0.0	6.8	0.0	0.0	5.4
Determine Route	Copilot	15	0.0	6.8	0.0	0.0	7.0
Determine Wind Direction	Copilot	5	0.0	5.3	0.0	0.0	0.0
Dispense Countermeasures	Copilot	2	0.0	1.2	2.2	0.0	5.0
Emergency APU Start	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0
Ensure Floor Loading Limits Are Met	Copilot	60	0.0	4.6	0.0	0.0	7.0
Follow Course	Copilot	4	0.0	6.8	0.0	0.0	7.0
Identify LZ / Airfield	Pilot	5	0.0	6.8	0.0	0.0	7.0
Locate Supplemental LZ	Copilot	15	0.0	6.8	0.0	0.0	5.0
Maintain Obstacle Clearance	Copilot	2	0.0	1.0	0.0	0.0	7.0
Monitor Aircraft Survivability Equipment	Copilot	2	0.0	4.6	0.0	0.0	5.0
Monitor FM1	Copilot	4	6.0	5.3	0.0	0.0	0.0
Monitor FM2	Copilot	4	6.0	5.3	0.0	0.0	0.0
Monitor GPS Display	Copilot	4	0.0	6.8	0.0	0.0	5.4
Monitor Loading	Copilot	90	0.0	1.2	0.0	0.0	7.0
Monitor UHF	Copilot	4	6.0	5.3	0.0	0.0	0.0
Monitor Unloading	Copilot	10	0.0	1.2	0.0	0.0	7.0
Monitor VHF	Pilot	4	6.0	5.3	0.0	0.0	0.0
Note Time	Copilot	4	0.0	4.6	2.2	0.0	5.0
Pilot Sector Scan	Pilot	4	0.0	6.8	0.0	0.0	7.0
Press GPS Data Entry Key	Copilot	2	0.0	1.2	2.2	0.0	5.0
Press GPS Keyboard Key	Copilot	2	0.0	1.2	2.2	0.0	5.0
Read Maps	Copilot	5	0.0	6.8	4.6	0.0	5.4
Receive FRAGO via FM	Copilot	18	6.0	5.3	0.0	0.0	0.0
Receive Internal Radio Call	Pilot	3	6.0	5.3	0.0	0.0	0.0
Receive Message (CP)	Copilot	random	6.0	5.3	0.0	0.0	0.0
Receive Message (P)	Pilot	random	6.0	5.3	0.0	0.0	0.0
Receive Message	Copilot / Pilot	random	6.0	5.3	0.0	0.0	0.0
Reset #1, 2 Generator Switches	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0
Reset Master Caution Indicator	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0
Set Chaff Dispenser Arm Switch	Copilot	2	0.0	1.2	2.2	0.0	5.0
Set Fly to Destination Waypoint	Copilot	2	0.0	1.2	2.2	0.0	5.0
Set Infrared Countermeasures	Copilot	2	0.0	1.2	2.2	0.0	5.0
Set Radar Jamming Control Switch	Copilot	2	0.0	1.2	2.2	0.0	5.0
Set Transmitter Selector Switch	Copilot / Pilot	2	0.0	1.2	2.2	0.0	5.0
Transmit Acknowledgement	Copilot / Pilot	2	0.0	5.3	0.0	2.0	0.0
Transmit (CP)	Copilot	random	0.0	5.3	0.0	4.0	0.0
Transmit (P)	Pilot	random	0.0	5.3	0.0	4.0	0.0
Transmit Message	Copilot / Pilot	random	0.0	5.3	0.0	4.0	0.0
Turn Off #1, 2 Generator Switches	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0
Turn Off SAS1 Switch	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0
Turn On #1, 2 Generator Switches	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0
Turn On SAS1 Switch	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0
Verify Satellite Coverage	Copilot	3	0.0	4.6	0.0	0.0	5.0
Verify Load Secure	Copilot	10	0.0	1.2	0.0	0.0	5.0
Verify Performance Data	Pilot	5	0.0	4.6	0.0	0.0	5.0
Verify Reserve Fuel Quantity	Copilot	3	0.0	7.0	0.0	0.0	5.0
Verify Unloading Complete	Copilot	3	0.0	4.6	0.0	0.0	7.0

Figure 6: Current UH-60 Resource Values

**Appendix J - IMPRINT Resource Assignment Values for Alternate
UH-60**

Air Assault Resource Assignment Values for Alternate Cockpit								
Task	Primary	Est. Time	Audio	Cognitive	Fine Motor	Speech	Visual	Tactile
Acknowledge FRAGO	Copilot	10	0.0	5.3	0.0	4.0	0.0	0.0
Adjust Power	Pilot	1	0.0	4.6	2.6	0.0	0.0	0.0
Adjust Trim	Pilot	1	0.0	4.6	2.6	0.0	0.0	0.0
Check Airspeed Indicator	Pilot	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Airspeed Indicator (LI)	Pilot	2	0.0	1.2	0.0	0.0	0.0	2.0
Check Altimeter	Pilot	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Altimeter (H/L)	Pilot	2	0.0	1.2	0.0	0.0	0.0	2.0
Check Armor Panel	Pilot	1	0.0	1.0	0.0	0.0	5.0	0.0
Check Crew (Visual)	Copilot	4	0.0	1.2	0.0	0.0	5.0	0.0
Check Doors	Copilot	5	0.0	1.2	0.0	0.0	5.0	0.0
Check Drift	Pilot	4	0.0	1.2	0.0	0.0	0.0	2.0
Check Engine 1 RPM	Copilot	1	0.0	4.6	0.0	0.0	5.0	0.0
Check Engine 2 RPM	Copilot	1	0.0	4.6	0.0	0.0	5.0	0.0
Check Flight Instruments	Pilot	7	0.0	4.6	0.0	0.0	7.0	0.0
Check Fuel Quantity Indicator	Both	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Groundspeed	Copilot	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Heading Indicator	Pilot	2	0.0	1.2	0.0	0.0	0.0	2.0
Check Master Caution / Advisory Panel	Copilot	2	0.0	6.8	0.0	0.0	5.0	0.0
Check Master Caution Indicator	Copilot	1	0.0	1.0	0.0	0.0	1.0	0.0
Check Obstacle Clearance	Copilot / Pilot	4	0.0	6.8	0.0	0.0	7.0	0.0
Check Parking Break	Copilot	2	0.0	1.2	0.0	0.0	5.0	0.0
Check Power Levers	Pilot	2	0.0	1.2	5.5	0.0	5.0	0.0
Check Radios (Visual)	Copilot	7	0.0	5.3	2.2	0.0	5.0	0.0
Check Rotor RPM	Copilot	1	0.0	4.6	0.0	0.0	5.0	0.0
Check Tailwheel Advisory Light	Copilot	1	0.0	1.2	0.0	0.0	5.0	0.0
Check Torque Indicator	Pilot	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Transponder	Copilot	1	0.0	1.0	0.0	0.0	5.0	0.0
Check Trim Ball	Pilot	2	0.0	1.2	0.0	0.0	0.0	2.0
Check VSI	Pilot	2	0.0	4.6	0.0	0.0	5.0	0.0
Check VSI (H/L)	Pilot	2	0.0	1.2	0.0	0.0	0.0	2.0
Compute Consumption Rate	Copilot	8	0.0	7.0	6.5	0.0	5.0	0.0
Control Airspeed	Pilot	3	0.0	4.6	2.6	0.0	0.0	0.0
Control Altitude	Pilot	1	0.0	4.6	2.6	0.0	0.0	0.0
Control Attitude	Pilot	1	0.0	4.6	2.6	0.0	0.0	0.0
Control Drift	Pilot	1	0.0	4.6	2.6	0.0	0.0	0.0
Control Heading	Pilot	1	0.0	4.6	2.6	0.0	0.0	0.0
Copilot Sector Scan	Copilot	4	0.0	6.8	0.0	0.0	7.0	0.0
Detect #1,2 Caution Lights	Copilot / Pilot	1	0.0	6.8	0.0	0.0	5.0	0.0
Depress Floor Handmike Switch (CP)	Copilot	0	0.0	0.0	0.0	0.0	0.0	0.0
Depress Floor Handmike Switch (PI)	Pilot	0	0.0	0.0	0.0	0.0	0.0	0.0
Detect Caution Lights Still On	Copilot / Pilot	1	0.0	1.0	0.0	0.0	5.0	0.0
Detect CMWS Warning	Copilot	1	1.0	1.0	0.0	0.0	0.0	2.0
Determine Enemy Location	Copilot	5	0.0	4.6	0.0	0.0	0.0	2.0
Determine Heading to ACPs	Copilot	3	0.0	6.8	0.0	0.0	5.0	0.0
Determine Landing Heading	Copilot	5	0.0	7.0	0.0	0.0	5.0	0.0
Determine Location	Copilot	5	0.0	6.8	0.0	0.0	5.4	0.0
Determine Route	Copilot	15	0.0	6.8	0.0	0.0	7.0	0.0
Determine Wind Direction	Copilot	5	0.0	5.3	0.0	0.0	0.0	0.0
Dispense Countermeasures	Copilot	2	0.0	1.2	2.2	0.0	5.0	0.0
Emergency APU Start	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0	0.0
Ensure Floor Loading Limits Are Met	Copilot	60	0.0	4.6	0.0	0.0	7.0	0.0
Follow Course	Copilot	4	0.0	4.6	0.0	0.0	0.0	2.0
Identify LZ / Airfield	Pilot	5	0.0	4.6	0.0	0.0	5.0	2.0
Locate Supplemental LZ	Copilot	15	0.0	4.6	0.0	0.0	5.0	2.0
Maintain Obstacle Clearance	Copilot	2	0.0	1.0	0.0	0.0	7.0	0.0
Monitor Aircraft Survivability Equipment	Copilot	2	0.0	4.6	0.0	0.0	5.0	0.0
Monitor FM1	Copilot	4	4.2	5.3	0.0	0.0	0.0	0.0
Monitor FM2	Copilot	4	4.2	5.3	0.0	0.0	0.0	0.0
Monitor GPS Display	Copilot	4	0.0	4.6	0.0	0.0	0.0	2.0
Monitor Loading	Copilot	90	0.0	1.2	0.0	0.0	7.0	0.0
Monitor UHF	Copilot	4	4.2	5.3	0.0	0.0	0.0	0.0
Monitor Unloading	Copilot	10	0.0	1.2	0.0	0.0	7.0	0.0
Monitor VHF	Copilot	4	4.2	5.3	0.0	0.0	0.0	0.0
Note Time	Copilot	4	0.0	4.6	2.2	0.0	5.0	0.0
Pilot Sector Scan	Pilot	4	0.0	6.8	0.0	0.0	7.0	0.0
Press GPS Data Entry Key	Copilot	2	0.0	1.2	2.2	0.0	5.0	0.0
Press GPS Keyboard Key	Copilot	2	0.0	1.2	2.2	0.0	5.0	0.0
Read Maps	Copilot	5	0.0	6.8	4.6	0.0	5.4	0.0
Receive FRAGO via FM	Copilot	18	4.2	5.3	0.0	0.0	0.0	0.0
Receive Internal Radio Call	Pilot	3	4.2	5.3	0.0	0.0	0.0	0.0
Receive Message (CP)	Copilot	random	4.2	5.3	0.0	0.0	0.0	0.0
Receive Message (PI)	Pilot	random	4.2	5.3	0.0	0.0	0.0	0.0
Receive Message	Copilot	random	4.2	5.3	0.0	0.0	0.0	0.0
Reset #1,2 Generator Switches	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0	0.0
Reset Master Caution Indicator	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0	0.0
Set Chaff Dispenser Arm Switch	Copilot	2	0.0	1.2	2.2	0.0	5.0	0.0
Set Fly to Destination Waypoint	Copilot	2	0.0	1.2	2.2	0.0	5.0	0.0
Set Infrared Countermeasures	Copilot	2	0.0	1.2	2.2	0.0	5.0	0.0
Set Radar Jamming Control Switch	Copilot	2	0.0	1.2	2.2	0.0	5.0	0.0
Set Transmitter Selector Switch	Copilot	2	0.0	1.2	2.2	0.0	5.0	0.0
Transmit Acknowledgement	Copilot	2	0.0	5.3	0.0	2.0	0.0	0.0
Transmit (CP)	Copilot	random	0.0	5.3	0.0	4.0	0.0	0.0
Transmit (PI)	Pilot	random	0.0	5.3	0.0	4.0	0.0	0.0
Transmit Message	Copilot	random	0.0	5.3	0.0	4.0	0.0	0.0
Turn Off #1,2 Generator Switches	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0	0.0
Turn Off SAS1 Switch	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0	0.0
Turn On #1,2 Generator Switches	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0	0.0
Turn On SAS1 Switch	Copilot / Pilot	2	0.0	1.2	2.2 / 0	0.0	5.0	0.0
Verify Satellite Coverage	Copilot	3	0.0	4.6	0.0	0.0	5.0	0.0
Verify Load Secure	Copilot	10	0.0	1.2	0.0	0.0	5.0	0.0
Verify Performance Data	Pilot	5	0.0	4.6	0.0	0.0	5.0	0.0
Verify Reserve Fuel Quantity	Copilot	3	0.0	7.0	0.0	0.0	5.0	0.0
Verify Unloading Complete	Copilot	3	0.0	4.6	0.0	0.0	7.0	0.0

Figure 7: Alternate UH-60 Resource Values

Appendix K - IMPRINT Resource Assignment Values for Current AH-64D

Apache Resource Assignment Values for Current Cockpit							
Task	Primary	Est. Time	Audio	Cognitive	Fine Motor	Speech	Visual
A/S Button to Arm	CPG	2	0.0	1.2	2.2	0.0	5.0
A/S Button to Safe	Ph	2	0.0	1.2	2.2	0.0	5.0
Acknowledge (Action) Master Caution	Ph	2	0.0	1.2	2.2	0.0	5.0
Adjust Power	Ph	1	0.0	4.6	2.6	0.0	0.0
Adjust Trim	Ph	1	0.0	4.6	2.6	0.0	0.0
Check Altitude Endurance	CPG	2	0.0	4.6	0.0	0.0	5.0
Check Airspeed	Ph	2	0.0	4.6	0.0	0.0	5.0
Check Altitude	Ph	2	0.0	4.6	0.0	0.0	5.0
Check Drift	Ph	4	0.0	6.8	0.0	0.0	7.0
Check Eng 1,2 Gas Generator Speed	CPG	2	0.0	4.6	0.0	0.0	5.0
Check Eng 1,2 Gas Temp	CPG	2	0.0	4.6	0.0	0.0	5.0
Check Eng 1,2 Torque	CPG	2	0.0	4.6	0.0	0.0	5.0
Check Eng 1,2 Turbine Speed	CPG	2	0.0	4.6	0.0	0.0	5.0
Check Flight Instruments	Ph	5	0.0	4.6	0.0	0.0	7.0
Check Fuel Flow	CPG	2	0.0	4.6	0.0	0.0	5.0
Check Fuel Quantity	CPG	2	0.0	4.6	0.0	0.0	5.0
Check Heading Indicator	Ph	2	0.0	4.6	0.0	0.0	5.0
Check Main Rotor Speed	CPG	2	0.0	4.6	0.0	0.0	5.0
Check Obstacle Clearance	Ph / CPG	4	0.0	6.8	0.0	0.0	7.0
Check Rate of Climb	Ph	2	0.0	4.6	0.0	0.0	5.0
Check Rate of Descent	Ph	2	0.0	4.6	0.0	0.0	5.0
Check Torque	Ph	2	0.0	4.6	0.0	0.0	5.0
Check Trim Ball	Ph	2	0.0	4.6	0.0	0.0	5.0
Check UFD Cautions	Ph	3	0.0	4.6	0.0	0.0	5.0
Check VSI	Ph	2	0.0	4.6	0.0	0.0	5.0
Check XPNDR	Ph	1	0.0	1.0	0.0	0.0	5.0
Compute Consumption Rate	CPG	8	0.0	7.0	6.5	0.0	5.0
Control Airspeed	Ph	1	0.0	4.6	2.6	0.0	0.0
Control Altitude	Ph	1	0.0	4.6	2.6	0.0	0.0
Control Attitude	Ph	1	0.0	4.6	2.6	0.0	0.0
Control Drift	Ph	1	0.0	4.6	2.6	0.0	0.0
Control Heading	Ph	1	0.0	4.6	2.6	0.0	0.0
CPG Scan Outside Cockpit	CPG	5	0.0	6.8	0.0	0.0	7.0
Detect Audio Tones	Ph / CPG	1	1.0	1.0	0.0	0.0	0.0
Detect Master Caution Illumination	Ph / CPG	1	0.0	1.0	0.0	0.0	5.0
Determine Angle of Attack	Ph	5	0.0	6.8	0.0	0.0	0.0
Determine Attack Pattern	Ph	5	0.0	6.8	0.0	0.0	0.0
Determine Attack Technique	Ph	5	0.0	6.8	0.0	0.0	0.0
Determine Munitions	Ph	5	0.0	6.8	0.0	0.0	0.0
Engine 1 Power Lever to IDLE	Ph	3	0.0	4.6	5.5	0.0	0.0
Enter Airfield Location with Cursor	CPG	6	0.0	1.2	4.6	0.0	5.0
Enter Location of WP w/ Cursor	CPG	6	0.0	6.8	4.6	0.0	5.0
Establish Range to Target	CPG	2	0.0	1.2	2.2	0.0	5.0
Follow Course	CPG	4	0.0	6.8	0.0	0.0	7.0
GROUNDIDE Button Off	Ph	2	0.0	1.2	2.2	0.0	5.0
Increase Power	Ph	3	0.0	4.6	5.5	0.0	0.0
Lock Tail Wheel Button	Ph	2	0.0	1.2	2.2	0.0	5.0
Maintain Obstacle Clearance	CPG	2	0.0	1.0	0.0	0.0	7.0
Master ARM / SAFE - Arm	Ph	2	0.0	4.6	2.2	0.0	5.0
Monitor Camera	CPG	4	0.0	6.8	0.0	0.0	7.0
Monitor FMI	CPG	4	6.0	5.3	0.0	0.0	0.0
Monitor FM2	Ph	4	6.0	5.3	0.0	0.0	0.0
Monitor HF	Ph	4	6.0	5.3	0.0	0.0	0.0
Monitor Master Caution	Ph / CPG	2	0.0	1.0	0.0	0.0	5.0
Monitor Sights / Route	CPG	4	0.0	6.8	0.0	0.0	7.0
Monitor TSD Display	CPG	4	0.0	6.8	0.0	0.0	7.0
Monitor UHF	CPG	4	6.0	5.3	0.0	0.0	0.0
Monitor VHF	Ph	4	6.0	5.3	0.0	0.0	0.0
Monitor Warning Systems	CPG	4	0.0	6.8	0.0	0.0	5.0
Note Time	CPG	4	0.0	4.6	2.2	0.0	5.0
Observe ENGINE1 CHIPSCaution	Ph / CPG	2	0.0	4.6	0.0	0.0	5.0
Observe ENGINE1 CHIPSCaution Light Off	Ph / CPG	2	0.0	4.6	0.0	0.0	5.0
Observe Round Impact	CPG	3	0.0	6.8	0.0	0.0	7.0
Pilot Scan Outside Cockpit	Ph	5	0.0	6.8	0.0	0.0	7.0
PLT Input Range Source	Ph	2	0.0	4.6	2.2	0.0	5.0
PLTWAS Gun	Ph	2	0.0	4.6	2.2	0.0	5.0
Press Trigger	CPG	1	0.0	1.2	2.2	0.0	0.0
Receive Message	Ph / CPG	random	6.0	5.3	0.0	0.0	0.0
Reselect Gun (Store)	CPG	2	0.0	1.2	2.2	0.0	5.0
Review WP / Route	CPG	6	0.0	6.8	0.0	0.0	5.0
Select ADD Button	CPG	2	0.0	1.2	2.2	0.0	5.0
Select ASE Page	CPG	2	0.0	1.2	2.2	0.0	5.0
Select ENG Button	CPG	2	0.0	1.2	2.2	0.0	5.0
Select Fuel Page	CPG	2	0.0	1.2	2.2	0.0	5.0
Select Gun Button	CPG	2	0.0	1.2	2.2	0.0	5.0
Select IDENT Button	CPG	2	0.0	1.2	2.2	0.0	5.0
Select PERF Page	CPG	2	0.0	1.2	2.2	0.0	5.0
Select POINT Button	CPG	2	0.0	1.2	2.2	0.0	5.0
Select RTE Page	CPG	2	0.0	1.2	2.2	0.0	5.0
Select RWI Button	CPG	2	0.0	1.2	2.2	0.0	5.0
Select SEND Button	CPG	2	0.0	1.2	2.2	0.0	5.0
Select Sight	CPG	2	0.0	1.2	2.2	0.0	5.0
Select STO Button	CPG	2	0.0	1.2	2.2	0.0	5.0
Select WP3w/ Cursor	CPG	2	0.0	1.2	4.6	0.0	5.0
Select WP4w/ Cursor	CPG	2	0.0	1.2	4.6	0.0	5.0
Select WPN Page	CPG	2	0.0	1.2	2.2	0.0	5.0
Select WPT Button	CPG	2	0.0	1.2	2.2	0.0	5.0
Select WPT Page	CPG	2	0.0	1.2	2.2	0.0	5.0
Select XMP Button	CPG	2	0.0	1.2	2.2	0.0	5.0
Set ASE	Ph	5	0.0	6.8	2.2	0.0	5.0
Set Parking Brake	Ph	2	0.0	1.2	2.2	0.0	5.0
Set Power Levers to Fly	Ph	3	0.0	1.2	5.5	0.0	5.0
Set Transmitter Selector Switch	Ph / CPG	2	0.0	1.2	2.2	0.0	5.0
Toggle STORE Switch	CPG	2	0.0	1.2	2.2	0.0	5.0
Track Target w/ LOS Reticle	CPG	7	0.0	6.8	4.6	0.0	5.4
Transmit Acknowledgment	Ph / CPG	2	0.0	5.3	0.0	2.0	0.0
Transmit Message	Ph / CPG	random	0.0	5.3	0.0	4.0	0.0
Turn VC R On	CPG	2	0.0	4.6	2.2	0.0	5.0
Verify Reserve Fuel Quantity	CPG	3	0.0	7.0	0.0	0.0	5.0
Verify Weapons Not Actioned	CPG	2	0.0	1.2	2.2	0.0	5.0
Verify Fuel Quantity	Ph	3	0.0	7.0	0.0	0.0	5.0
Verify Performance Data	Ph	5	0.0	4.6	0.0	0.0	5.0
Visually Scan	CPG	4	0.0	6.8	0.0	0.0	7.0
WAS - Gun	CPG	2	0.0	1.2	2.2	0.0	5.0

Figure 8: Current AH-64D Resource Values

**Appendix L - IMPRINT Resource Assignment Values for Alternate
AH-64D**

Apache Resource Assignment Values for Alternate Cockpit								
Task	Primary	Est. Time	Audio	Cognitive	Fine Motor	Speech	Visual	Tactile
A/S Button to Arm	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
A/S Button to Safe	PR	2	0.0	1.2	2.2	0.0	5.0	0.0
Ac knowledge / Action in Master Caution	PR	2	0.0	1.2	2.2	0.0	5.0	0.0
Adjust Power	PR	1	0.0	4.6	2.6	0.0	0.0	0.0
Adjust Trim	PR	1	0.0	4.6	2.6	0.0	0.0	0.0
Check Air/galt Endurance	CPG	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Air/galt	PR	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Altitude	PR	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Altitude (H/L)	PR	2	0.0	1.2	0.0	0.0	0.0	2.0
Check Drift	PR	4	0.0	1.2	0.0	0.0	0.0	2.0
Check Eng 1/2 Gas Generator Speed	CPG	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Eng 1/2 Gas Temp	CPG	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Eng 1/2 Torque	CPG	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Eng 1/2 Turbine Speed	CPG	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Flight Instruments	PR	5	0.0	4.6	0.0	0.0	7.0	0.0
Check Fuel Flow	CPG	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Fuel Quantity	CPG	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Heading Indicator	PR	2	0.0	1.2	0.0	0.0	0.0	2.0
Check Main Motor Speed	CPG	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Obstacle Clearance	PR / CPG	4	0.0	6.8	0.0	0.0	7.0	0.0
Check Rate of Climb	PR	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Rate of Descent	PR	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Trim	PR	2	0.0	4.6	0.0	0.0	5.0	0.0
Check Trim Bell	PR	2	0.0	1.2	0.0	0.0	0.0	2.0
Check UFD Cautions	PR	3	0.0	4.6	0.0	0.0	5.0	0.0
Check VSI	PR	2	0.0	4.6	0.0	0.0	5.0	0.0
Check VSI (H/L)	PR	2	0.0	1.2	0.0	0.0	0.0	2.0
Check XP NDR	PR	1	0.0	1.0	0.0	0.0	5.0	0.0
Compute Consumption Rate	CPG	8	0.0	7.0	6.5	0.0	5.0	0.0
Control Airspeed	PR	1	0.0	4.6	2.6	0.0	0.0	0.0
Control Altitude	PR	1	0.0	4.6	2.6	0.0	0.0	0.0
Control Altitude	PR	1	0.0	4.6	2.6	0.0	0.0	0.0
Control Drift	PR	1	0.0	4.6	2.6	0.0	0.0	0.0
Control Heading	PR	1	0.0	4.6	2.6	0.0	0.0	0.0
CPG Scan Outside Cockpit	CPG	5	0.0	6.8	0.0	0.0	7.0	0.0
Detect Audio Tones	PR / CPG	1	1.0	1.0	0.0	0.0	0.0	0.0
Detect Master Caution Illumination	PR / CPG	1	0.0	1.0	0.0	0.0	5.0	0.0
Determine Angle of Attack	PR	5	0.0	6.8	0.0	0.0	0.0	0.0
Determine Attack Pattern	PR	5	0.0	6.8	0.0	0.0	0.0	0.0
Determine Attack Technique	PR	5	0.0	6.8	0.0	0.0	0.0	0.0
Determine Munitions	PR	5	0.0	6.8	0.0	0.0	0.0	0.0
Engine 1 Power Lever to Idle	PR	3	0.0	4.6	5.5	0.0	0.0	0.0
Enter Airfield Location with Cursor	CPG	6	0.0	1.2	4.6	0.0	5.0	0.0
Enter Location of WP w/ Cursor	CPG	6	0.0	6.8	4.6	0.0	5.0	0.0
Establish Range to Target	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Follow Course	CPG	4	0.0	4.6	0.0	0.0	0.0	2.0
GO DOWN Button Off	PR	2	0.0	1.2	2.2	0.0	5.0	0.0
Mainly Airfield	PR	5	0.0	4.6	0.0	0.0	5.0	2.0
Increase Power	PR	3	0.0	4.6	5.5	0.0	0.0	0.0
Lock Tail Wheel Button	PR	2	0.0	1.2	2.2	0.0	5.0	0.0
Main in Obstacle Clearance	CPG	2	0.0	1.0	0.0	0.0	7.0	0.0
Master ARM / SAFE - Arm	PR	2	0.0	4.6	2.2	0.0	5.0	0.0
Monitor Camber	CPG	4	0.0	6.8	0.0	0.0	7.0	0.0
Monitor FM1	CPG	4	4.2	5.3	0.0	0.0	0.0	0.0
Monitor FM2	PR	4	4.2	5.3	0.0	0.0	0.0	0.0
Monitor HF	PR	4	4.2	5.3	0.0	0.0	0.0	0.0
Monitor Master Caution	PR / CPG	2	0.0	1.0	0.0	0.0	5.0	0.0
Monitor Lights / No state	CPG	4	0.0	6.8	0.0	0.0	7.0	0.0
Monitor NO Display	CPG	4	0.0	6.8	0.0	0.0	7.0	0.0
Monitor UHF	CPG	4	4.2	5.3	0.0	0.0	0.0	0.0
Monitor VHF	PR	4	4.2	5.3	0.0	0.0	0.0	0.0
Monitor Warning Systems	CPG	4	0.0	1.2	0.0	0.0	0.0	2.0
Note Time	CPG	4	0.0	4.6	2.2	0.0	5.0	0.0
Observe ENGINE CHIPS Caution	PR / CPG	2	0.0	4.6	0.0	0.0	5.0	0.0
Observe ENGINE CHIPS Caution Light Off	PR / CPG	2	0.0	4.6	0.0	0.0	5.0	0.0
Observe Round Impact	CPG	3	0.0	6.8	0.0	0.0	7.0	0.0
Pilot Scan Outside Cockpit	PR	5	0.0	6.8	0.0	0.0	7.0	0.0
PLT Input Range Source	PR	2	0.0	4.6	2.2	0.0	5.0	0.0
PLTWAS Gun	PR	2	0.0	4.6	2.2	0.0	5.0	0.0
Press Trigger	CPG	0.0	1.2	2.2	0.0	0.0	0.0	0.0
Receive Message	PR / CPG random	PR	4.2	5.3	0.0	0.0	0.0	0.0
Receive FRAGO via FM	PR	18	4.2	5.3	0.0	0.0	0.0	0.0
Reselect Gun (Store)	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Review WP / Route	CPG	6	0.0	6.8	0.0	0.0	5.0	0.0
Select ADD Button	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select ASE Page	CPG	0	0.0	0.0	0.0	0.0	0.0	0.0
Select ENG Button	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select Fuel Page	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select Gun Button	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select IDENT Button	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select PERF Page	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select POINT Button	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select RTE Page	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select RVW Button	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select SEND Button	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select Sight	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select STO Button	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select WP 3w/ Cursor	CPG	2	0.0	1.2	4.6	0.0	5.0	0.0
Select WP 4w/ Cursor	CPG	2	0.0	1.2	4.6	0.0	5.0	0.0
Select WP N Page	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select WPT Button	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select WPT Page	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Select XMIT Button	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Set ASE	PR	5	0.0	6.8	2.2	0.0	5.0	0.0
Set Parking Brake	PR	2	0.0	1.2	2.2	0.0	5.0	0.0
Set Power Levers to Fly	PR	3	0.0	1.2	5.5	0.0	5.0	0.0
Set Transmitter Selector Switch	PR / CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Toggle STORE Switch	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Track Target w/ LOS Handle	CPG	7	0.0	6.8	4.6	0.0	5.4	0.0
To Transmit Acknowledgment	PR / CPG	2	0.0	5.3	0.0	2.0	0.0	0.0
Transmit Message	PR / CPG random	0.0	5.3	0.0	4.0	0.0	0.0	0.0
Turn VCR On	CPG	2	0.0	4.6	2.2	0.0	5.0	0.0
Verify Reserve Fuel Quantity	CPG	3	0.0	7.0	0.0	0.0	5.0	0.0
Verify Weapons Not Actuated	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0
Verify Fuel Quantity	PR	3	0.0	7.0	0.0	0.0	5.0	0.0
Verify Performance Data	PR	5	0.0	4.6	0.0	0.0	5.0	0.0
Visual Scan	CPG	4	0.0	6.8	0.0	0.0	7.0	0.0
WAS - Gun	CPG	2	0.0	1.2	2.2	0.0	5.0	0.0

Figure 9: Alternate AH-64D Resource Values

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